GE MARS Technical Session

December 1, 2025 Session

Mike Welch, Mitch Bringolf, Calvin Smythe, Fei Zeng
PLANNING SERVICES AND MARKET DEVELOPMENT

Introduction

- The purpose of this material is to explain how the MARS software's modeling capabilities are used to develop the ISO's Resource Adequacy Assessment (RAA) model and perform the assessments and calculations that support capacity market and system planning functions
  - This session does **not** address the rationale behind specific design choices or the validity of the input data assumptions used in the model
- The ISO has identified several topics of interest to stakeholders and will offer a second technical session on January 20, 2026
  - Today's session provides an overview of the MARS simulation process and the key modeling components used in a typical RAA model
  - The second session will focus on how the RAA model supports capacity market processes
- Pre-submitted questions will be addressed in the relevant content sections and additional questions may be discussed at the end of each section

MARS OVERVIEW

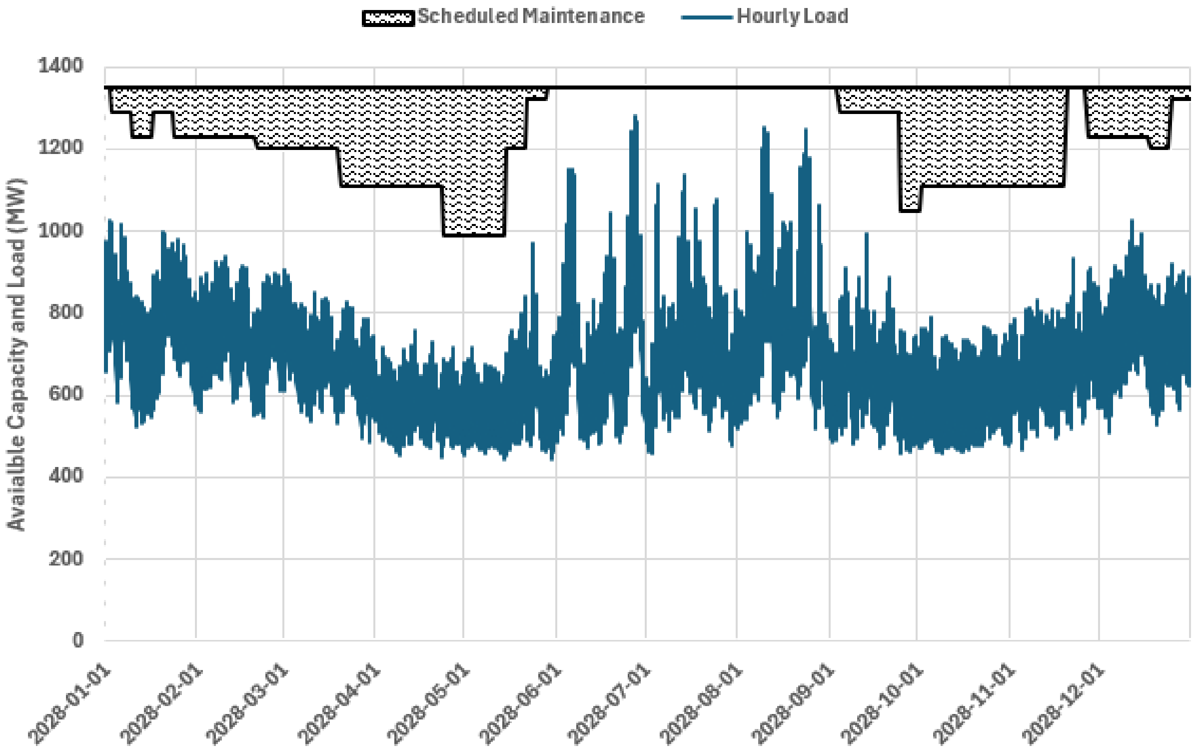
Test Model for This Training

- A test model was developed for the purpose of showcasing MARS functionalities with non-confidential data
  - Uses a single area representation
  - Uses a single load shape with five (5) uncertainty levels
  - Features representative resource types of thermal, wind, solar, and storage

Maintenance Scheduling

- Maintenance scheduling is the first operation MARS undergoes in the simulation process
- Typically, maintenance is only scheduled for thermal units, but it can be scheduled for other resources as well, for example: energy-limited resources, profile-based resources such as wind and solar
- The intent of the scheduling algorithm is to iteratively schedule maintenance in a predetermined order (such as total maintenance energy) to levelize reserves across the year
- Options are available to shape when maintenance can be scheduled
  - The ISO uses this option to avoid maintenance scheduled during peak summer months and peak winter months
- The outcome of this process is an hourly planned outage schedule for all resources, which will be applied in each replication of the simulation

Illustrative Total Planned Outages Scheduled from Test Model



Resource Availability – Thermal Resources

- At the beginning of the simulation, MARS evaluates the availability of each generator in the model to determine whether they are in-service or out-of-service for the first hour
- Subsequently, MARS relies on its sequential Monte Carlo process to determine generator capacity states
  - Detailed simulation process will be explained in the thermal resource modeling section
- The outcome of this process is an hourly simulated availability profile for every simulation year

Thermal Resource Simulated Hourly Availability

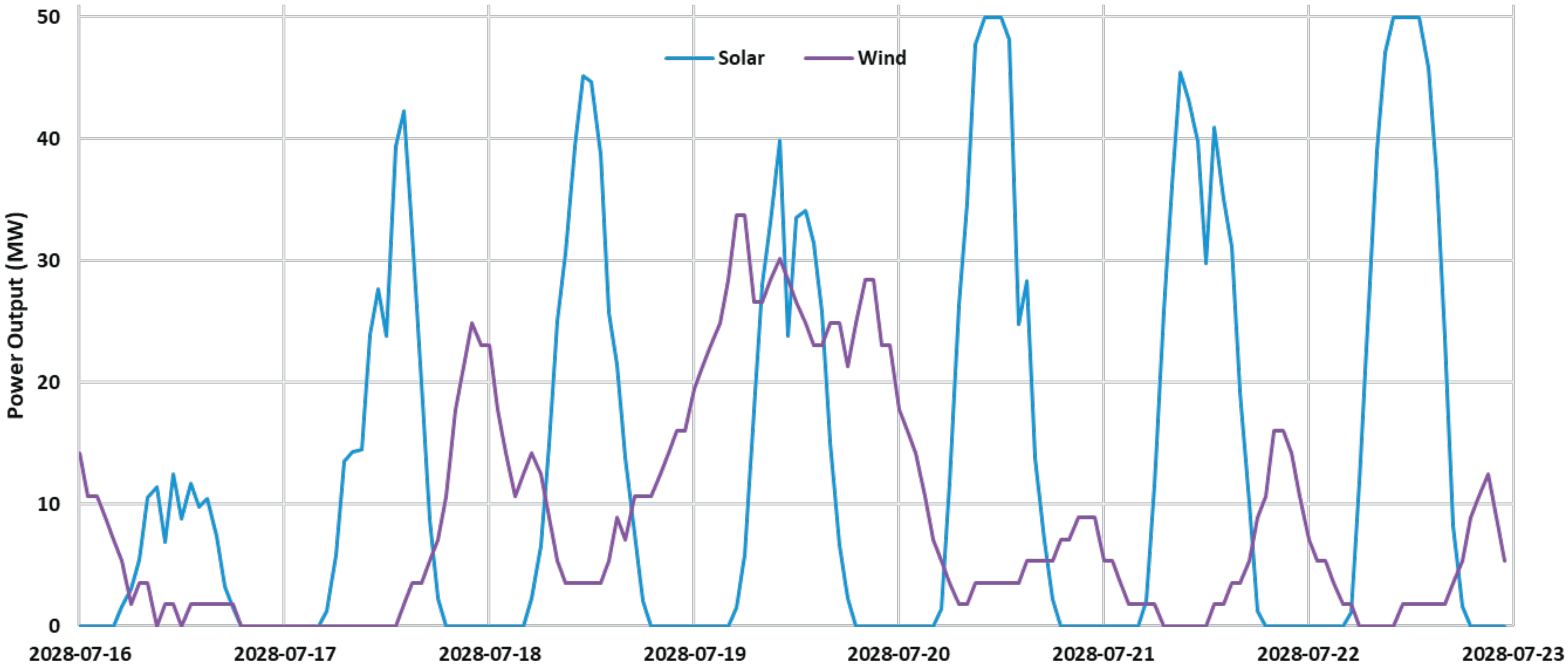
- Illustrative forced outage pattern simulated for a unit with a 5% forced outage rate

Target 5% Outage Rate	Hour of Year												Observed Outage Rate
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sample 1													19.95%
Sample 2													0.02%
Sample 3													15.20%
Sample 4													0.00%
Sample 5													0.00%
Sample 6													3.44%
Sample 7													9.02%
Sample 8													14.86%
Sample 9													2.69%
Sample 10													6.79%
First 10													7.19%
First 100													4.18%
First 1000													4.72%
First 10000													4.88%

Resource Availability – Profile Resources

- Unit output is normally set by the input profile(s), although forced and maintenance outages can be applied
- Some resources may use a single input profile
- Some resources may have multiple input profiles, each of which has an assigned probability of occurrence (typically equally weighted)
  - At the start of each replication, MARS will randomly draw one of those profiles, and it will be used for the whole year
  - A different profile may be drawn at the start of the next replication

Illustrative Profile Resource Hourly Output

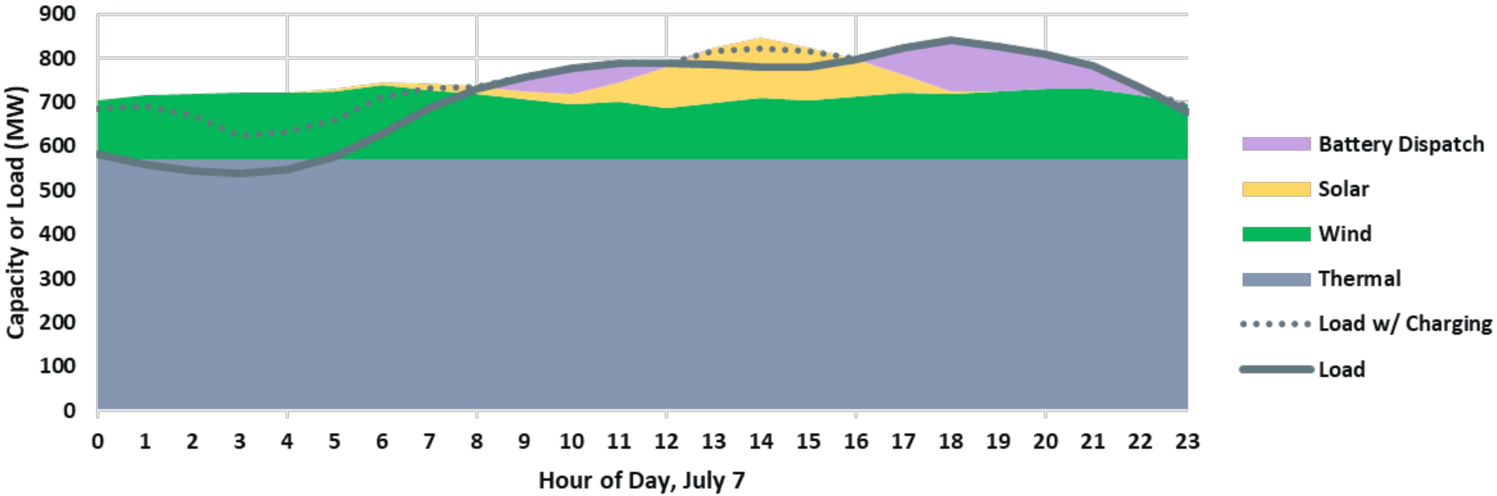


Resource Availability – Energy-Limited and Energy Storage Resources

- Unlike other resources that are treated as available as long as they are not on outages, energy storage and energy-limited resources can be dispatched to resolve loss of load events
- These units contain some amount of available energy and will be discharged on as-needed basis following the defined dispatch order until their energy is depleted, or the event is resolved

Energy Storage Output

- On this day, energy storage resources are dispatched to serve load (purple) and recharge in the overnight and mid-afternoon hours (dashed line)

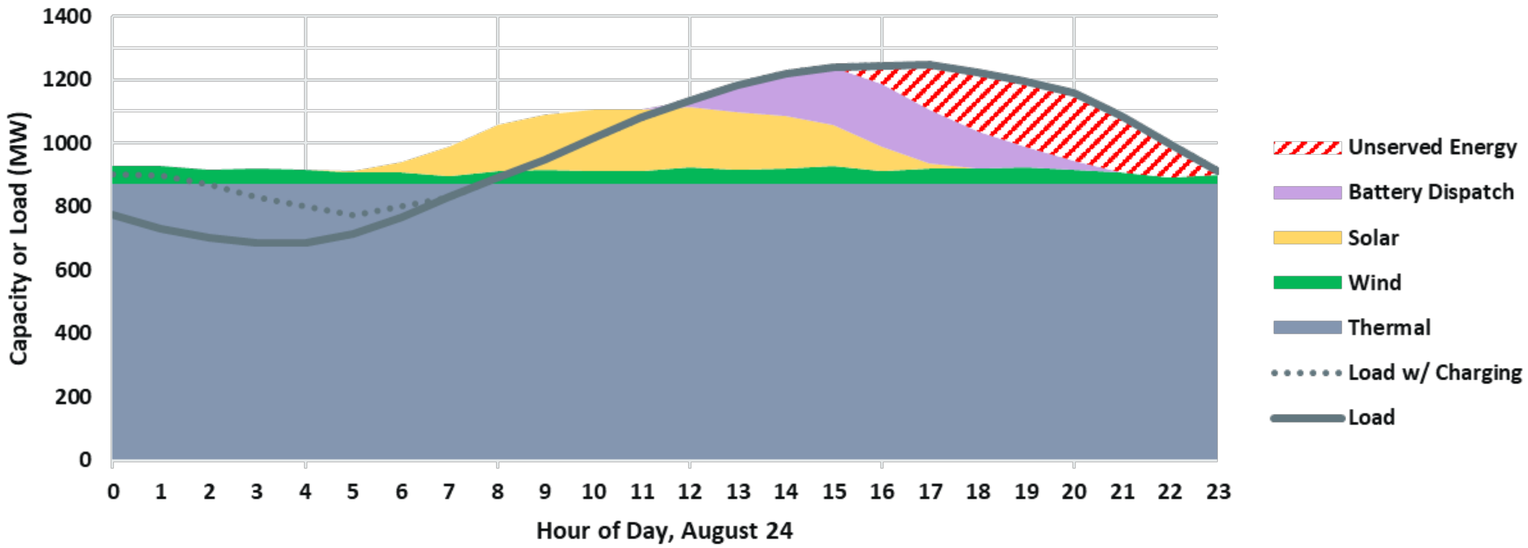


Resource Dispatch – Hourly Adequacy Assessment

- The graph on the next slide shows a select day where MARS utilizes available resources to serve the demand based on their availability
- Non-energy-limited resources (thermal, profiles) will be used first, adjusted for forced and maintenance outages
- If not adequate, MARS dispatches the energy-limited and energy storage resources
- If the dispatched capacity is insufficient to resolve the shortfall, then a loss-of-load event occurs
  - Each hour of the event will count as a loss of load hour
  - Each unique day an event occurs on will count as a loss of load day

Resource Dispatch – Hourly Adequacy Assessment, cont.

- The following figure shows a selected day from the test model, where the load exceeds the amount of available non-energy storage capacity, and MARS dispatches the batteries to serve the load. In this instance the storage capacity is insufficient to resolve the shortfall, resulting in a loss-of-load event.



Replications and Reliability Indices Calculations

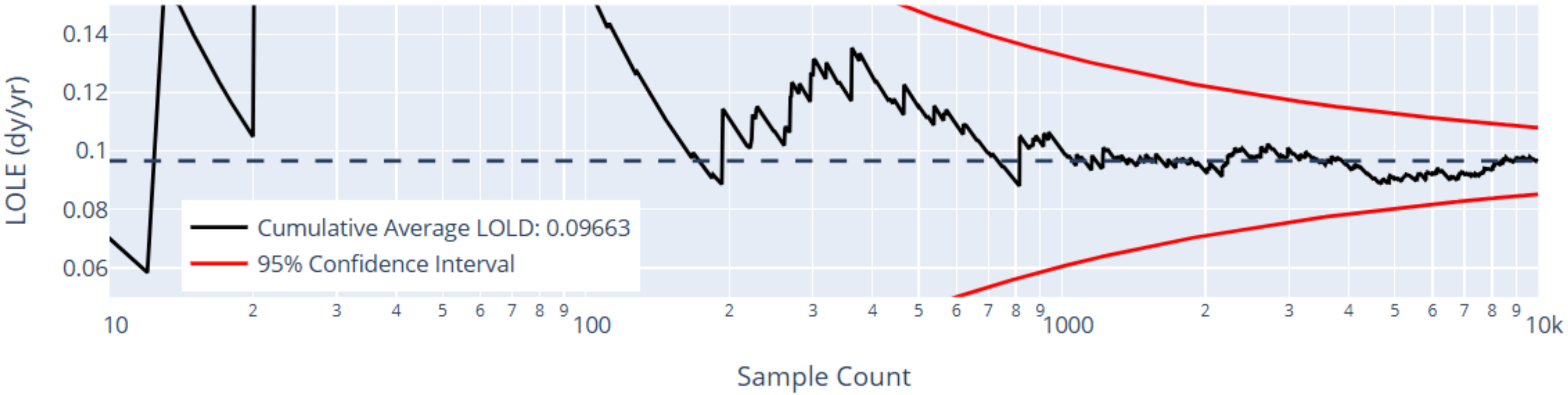
- At the beginning of the simulation (before the first sample), MARS will:
  - Generate the maintenance schedule
  - Determine the initial unit availability and begin creating the availability pattern for all units
- At the start of each replication (sample), MARS will:
  - Select which random profiles are being applied for profile-based units for the simulation year
  - Within each sample, MARS will:
    - Take units in and out of service based upon maintenance scheduled and forced outages simulated
    - Apply adjustments to system capacity for outages, hourly/monthly capacities
    - Evaluate each hour to see if energy-limited or energy storage resources need to be dispatched to serve the load, or recharge storage resources if surplus capacity is available
- At the end of each replication, MARS will:
  - Record the number of loss of load days/hours, and the amount of unserved energy
- When iterating to the next replication, MARS will:
  - Maintain capacity/outage state for units from the last hour of the previous replication
  - Reset energy limited and energy storage resources to their initial energy (typically full)

Simulation Convergence

- Simulation requires sufficient samples to produce converged results
- Convergence is defined in terms of the cumulative mean of the target reliability metric (typically Loss of Load Expectation (LOLE)) and is referred to as “standard error” in the MARS documentation and more generally as relative standard error (RSE)
- The table and graph on the next slide show how increasing the number of samples provides stability to the mean of LOLE and reduces the RSE

Simulation Convergence, cont.

Sample	Cumulative Mean LOLE (day/yr)	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Relative Standard Error (%)
10	0.0700	0.0000	0.2072	100.00
100	0.1580	0.0000	0.3640	66.51
1000	0.0999	0.0568	0.1430	22.00
10000	0.0966	0.0852	0.1081	6.04

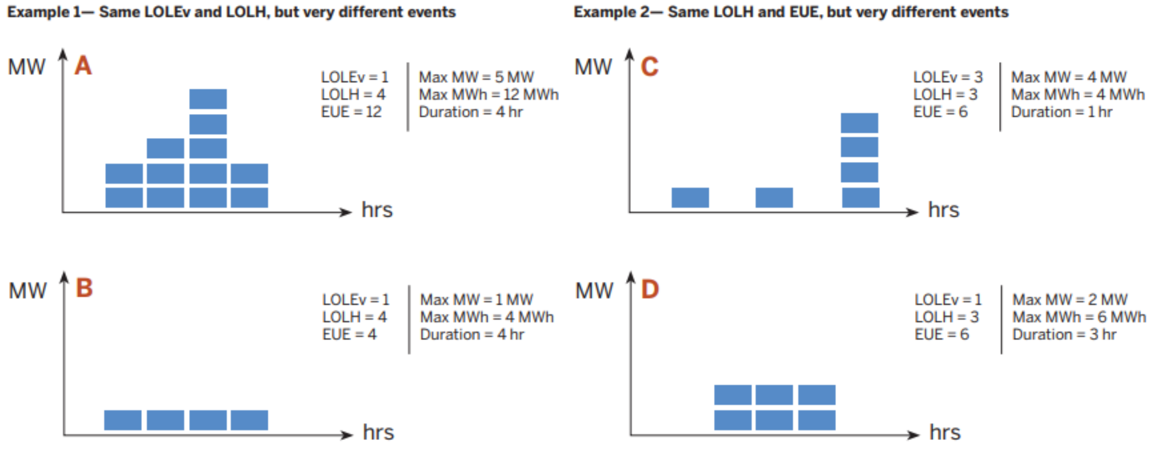


Resource Adequacy Metrics

- Three major resource adequacy metrics that MARS calculates
  – Loss of Load Expectation (LOLE) in day/year, also referred as LOLD
  – Loss of Load Hours (LOLH) in hours/year
  – Expected Unserved Energy (EUE) in MWh/year
- These metrics are considered expected values because they are based on averages of hundreds or thousands of samples
  – Result from each individual sample could be much larger or smaller than the expected value

Resource Adequacy Metrics, cont.

- Two systems that have the same adequacy level in one metric may have different risk levels for other metrics, as shown in this figure from [ESIG's Redefining Resource Adequacy Report]



Each block represents a one-hour duration of capacity shortfall, and the height of the stacks of blocks depicts the MW of unserved energy for each hour. A: a single, continuous four-hour shortfall with 12 MWh of unserved energy; B: a single, continuous four-hour shortfall with 4 MWh of unserved energy; C: three discrete one-hour shortfall events with 6 MWh of unserved energy; D: a single, continuous three-hour shortfall with 6 MWh of unserved energy.

Questions

THERMAL RESOURCE MODELING

Specifying Thermal Unit Parameters

- Data for Thermal units is input across several tables in MARS to set monthly capacity ratings, forced outage rates, and annual maintenance requirements
  – UNT-MXCP sets the maximum capacity
  – UNT-CAPS sets the rating for different capacity states used for simulating forced outages, in per unit of maximum rating
  – UNT-FORS sets the partial forced outage rate for each capacity state being modeled
    - UNT-FORS pairs with the NUM-TRNS table, which specifies how often units transition between capacity states
    - Alternatively, the UNT-TRNS table can be used to input the transition rates directly
  – MNT-UNOP is used to set the number of weeks a unit is required to be scheduled for maintenance in a year

Thermal Unit Parameters – UNT-MXCP

- In this example, each unit is modeled to have different ratings for the summer and winter season to represent how much capacity they can provide
  - For example, the first unit max capacity will be 30 MW for the winter months of January through April, then overridden to 26 MW for the summer months of May through October, then overridden again back to 30 MW for the remaining winter months of November and December

```
&UNT-MXCP-00       UMC
 *                 UNIT-MAXIMUM-CAPACITY-DATA
 *--------------------------------------------------------------
 *                                              MAXIMUM
 *   EFFECTIVE            UNIT                  RATING
 *     DATE               NAME                   (MW)
 *--------------------------------------------------------------
 *                                               .CAP.
 *--------------------------------------------------------------
 *     MMMYYYY         AAAAAAAA                   #
 *     -------         --------              ---------
 @     JAN2028         CC_1A                    30
 @     MAY2028         CC_1A                    26
 @     NOV2028         CC_1A                    30

 @     JAN2028         CC_2A                    60
 @     MAY2028         CC_2A                    52
 @     NOV2028         CC_2A                    60

 @     JAN2028         CC_3A                   120
 @     MAY2028         CC_3A                   104
 @     NOV2028         CC_3A                   120

 @     JAN2028         CC_4A                   240
 @     MAY2028         CC_4A                   208
 @     NOV2028         CC_4A                   240

;;;;
```

Thermal Unit Parameters – UNT-CAPS

- UNT-CAPS defines the capacity rating for different capacity states in per unit of maximum rating
- MARS supports modeling of multiple capacity states to reflect partial outages / forced derates and full outages, but currently the ISO models thermal units using two capacity states
- This table pairs with either the UNT-FORS or UNT-TRNS tables, which specify outage characteristics

```
&UNT-CAPS-00      UCS     CONTINUATION
 *                            CAPACITY-STATES
 *------------------------------------------------------------------------------
 *      EFFECTIVE      UNIT NAME      RATING OF EACH CAPACITY STATE IN PER
 *        YEAR                                  UNIT OF MAXIMUM RATING
 *------------------------------------------------------------------------------
 *                                                    .STATPU.
 *------------------------------------------------------------------------------
 *        YYYY         AAAAAAAA    ########  ########  ########  ########
 *        ----         --------    --------  --------  --------  --------
 @        2028         CC_1A       1         0
 @        2028         CC_2A       1         0
 @        2028         CC_3A       1         0
 @        2028         CC_4A       1         0
;;;
```

- In this example, the four units shown are all modeled in two capacity states: either at 100% output when available or 0% output when unavailable

Thermal Unit Parameters – UNT-TRNS

- MARS uses transition rates (specified in the UNT-TRNS) to simulate how each unit transitions between different capacity states due to outages
  - For a 2-state unit as shown in this example, the unit is either fully available or on full outage
- The rating for each capacity state is specified in UNT-CAPS

```
&UNT-TRNS-00      UTR     CONTINUATION
 *                        TRANSITION-RATE-DATA
 *-----------------------------------------------------------------------------
 *                     NUMBER
 * EFFECTIVE             OF     FROM       - -  TRANSITION RATE TO STATE  - -
 *   DATE       NAME   STATES  STATE        1          2          3          4
 *-----------------------------------------------------------------------------
 *  MMMYYYY  AAAAAAAA    I       I          #          #          #          #
 *  -------  --------   ---     ---     --------   --------   --------   --------
 @  JAN2028  CC_1A       2       1      0.000000   0.000116
 +                               2      0.005708   0.000000

 @  JAN2028  CC_1B       2       1      0.000000   0.000120
 +                               2      0.002283   0.000000

 @  JAN2028  CC_1C       2       1      0.000000   0.000124
 +                               2      0.001427   0.000000

;;;;
```

```
&UNT-CAPS-00      UCS     CONTINUATION
 *                              CAPACITY-STATES
 *----------------------------------------------------------------------------
 *      EFFECTIVE       UNIT NAME       RATING OF EACH CAPACITY STATE IN PER
 *         YEAR                                  UNIT OF MAXIMUM RATING
 *----------------------------------------------------------------------------
 *                                                     .STATPU.
 *----------------------------------------------------------------------------
 *         YYYY          AAAAAAAA    ########  ########  ########  ########
 *         ----          --------    --------  --------  --------  --------
 @         2028          CC_1A       1         0
 @         2028          CC_2A       1         0
 @         2028          CC_3A       1         0
 @         2028          CC_4A       1         0
;;;
```

Thermal Unit Parameters – UNT-FORS

- Alternatively, MARS can take forced outage rates (specified in UNT-FORS) and the expected number of transitions between states (specified in NUM-TRNS) and calculate the transition rates between states internally
- The UNT-FORS and NUM-TRNS are linked through the index of TRANSITION MATRIX in both tables.
  - For example, unit CC_1A has a 2% EFORd, and the TRANSITION MATRIX index value of "1" points to NUM-TRNS table that shows that this unit has two states and the expected number of transitions between these two states is 1
- The capacity rating for each capacity state is specified in UNT-CAPS

```
&UNT-FORS-00     UFO    CONTINUATION     ASTERISK
 *                                                    FORCED-OUTAGE-RATE-DATA
 *-------------------------------------------------------------------------------
 *                                               PARTIAL FORCED OUTAGE RATE
 *  EFFECTIVE             TRANSITION     - - - - - FOR CAPACITY STATE - - - - -
 *    DATE         NAME     MATRIX            1         2         3         4
 *-------------------------------------------------------------------------------
 *                           .ITRNSM.
 *-------------------------------------------------------------------------------
 *   MMMYYYY    AAAAAAAA      I               #         #         #         #
 *   -------    --------     ---          -------   -------   -------   -------
 @   JAN2028    CC_1A         1             0.02
 @   JAN2028    CC_1B         1             0.05
 @   JAN2028    CC_1C         1             0.08
;;;;


&NUM-TRNS-00     NTR    CONTINUATION
 *                                                  STATE-TRANSITION-DATA
 *---------------------------------------------------------------------------
 *                              NUMBER                      NUMBER OF TRANSITIONS
 * EFFECTIVE    TRANSITION       OF       FROM          - - - -  TO STATE  - - - -
 *   DATE         MATRIX       STATES     STATE           1       2       3       4
 *---------------------------------------------------------------------------
 *   YYYY            I            I         I             I       I       I       I
 *   ----          -----        -----     -----         -----   -----   -----   -----

 @   2028            1            2         1             0       1
 +                                          2             1       0

;;;;
```

Thermal Unit Parameters – MNT-UNOP/MNT-FIXD

- Annual maintenance requirements are specified in MNT-UNOP
  - In this example, the units are set to either 2 or 4 weeks of maintenance in 2028

```
&MNT-UNOP-00     UMO
 *                                                   UNIT-MAINTENANCE-OPTIONS
 *-------------------------------------------------------------------------------------------------------------
 *                                                 MAINTENANCE
 *                                                  WEEKS OR
 *                                                    CYCLE            STARTING          MAINT        MAINT
 *                                 OVERRIDE MAINT.  0 = NO MAINT.    POSITION IN        WINDOW       WINDOW
 *   EFFECTIVE      UNIT            SCHED. FROM    <0 = # OF WEEKS   MAINT. CYCLE       START        STOP
 *     YEAR         NAME            INTERFACE ?    >0 = CYCLE #         (1-7)           DATE         DATE
 *-------------------------------------------------------------------------------------------------------------
 *     YYYY      "AAAAAAAA"           Y/N              III                I             DDMMM        DDMMM
 *     ----       --------            ---              ---               ---            -----        -----
 @     2028        CC_1A               N                -2                1               =            =
 @     2028        CC_2A               N                -2                1               =            =
 @     2028        CC_3A               N                -4                1               =            =
 @     2028        CC_4A               N                -4                1               =            =
;;;
```

- Alternatively, if maintenance dates are known they can be input into the MNT-FIXD table and it will override the MNT-UNOP entry

Forced Outage Rates Realization in MARS (1)

- The sequential Monte Carlo engine used in MARS randomly places units in and out of service based on input forced outage rate parameters
  - MARS does not require that a unit with a 10% outage rate be out of service for 876 hours each simulation year
  - Instead, the unit will be in or out of service for some amount of time based on the input outage rate, with the expectation that over a long enough time horizon, the observed outage rate will converge to the input value
- MARS uses a pseudo random number generator to simulate the random outages. The same seed will always produce the exact same sequence of random numbers, thus results in the same realized outage pattern, which can make MARS results repeatable
- **NOTE:** The terms "outage rate" and "EFORd" may be used interchangeably
  - EFORd: Equivalent Forced Outage Rate, demand-weighted

Forced Outage Rates Realization in MARS (2)

- The next several slides use three units with different forced outage rates to show:
  - As the sample count increases, the observed outage rate is converging towards the input value
  - How the simulated availability/outage patterns change as a function of the outage rate
- Each slide will show:
  - The sample-level unavailability (gray) for the first 10 samples, and
  - The average hourly unavailability (shades of red) for the first 10, 100, 1000, and 10,000 samples

Example Outage Pattern for Unit CC_1A

- This unit has a 2% outage rate

Target 2% Outage Rate	Hour of Year												Observed Outage Rate
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sample 1													0.00%
Sample 2													4.39%
Sample 3													3.47%
Sample 4													0.00%
Sample 5													0.00%
Sample 6													3.12%
Sample 7													1.94%
Sample 8													0.00%
Sample 9													0.00%
Sample 10													0.00%
First 10													1.29%
First 100													1.68%
First 1000													1.95%
First 10000													2.02%

Example Outage Pattern for Unit CC_1B

- This unit has a 5% outage rate

Target 5% Outage Rate	Hour of Year												Observed Outage Rate
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sample 1													19.95%
Sample 2													0.02%
Sample 3													15.20%
Sample 4													0.00%
Sample 5													0.00%
Sample 6													3.44%
Sample 7													9.02%
Sample 8													14.86%
Sample 9													2.69%
Sample 10													6.79%
First 10													7.19%
First 100													4.18%
First 1000													4.72%
First 10000													4.88%

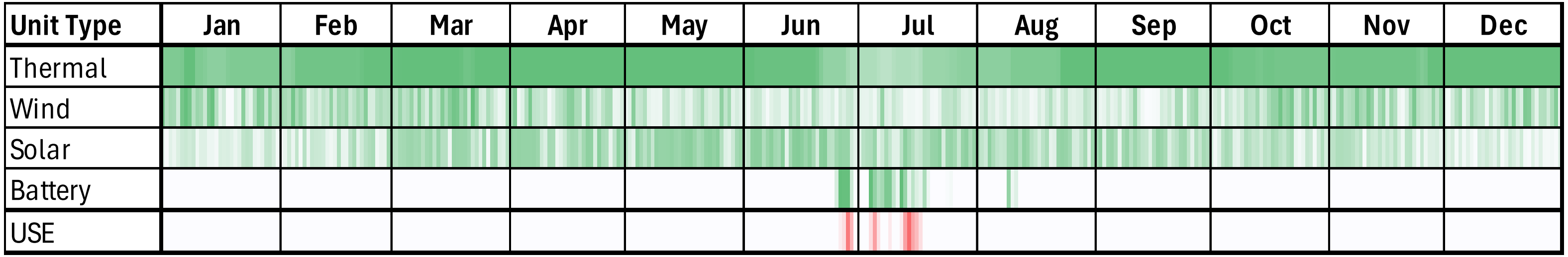
Example Outage Pattern for Unit CC_1C

- This unit has an 8% outage rate

Target 8% Outage Rate	Hour of Year												Observed Outage Rate
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sample 1													43.75%
Sample 2													28.26%
Sample 3													7.05%
Sample 4													11.40%
Sample 5													0.00%
Sample 6													0.00%
Sample 7													22.89%
Sample 8													1.04%
Sample 9													0.00%
Sample 10													2.56%
First 10													11.69%
First 100													8.85%
First 1000													9.02%
First 10000													8.10%

Outage Impacts on Loss-of-Load Events

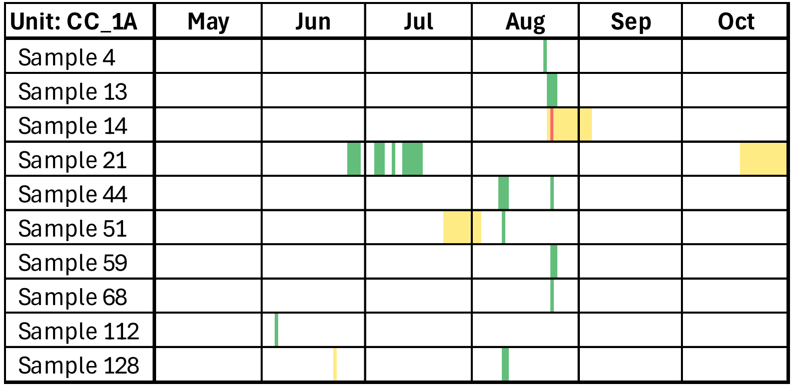
- Typically, it requires multiple, simultaneous outages to result in a loss-of-load event
- In the figure below, the green shading indicates the amount of resource capacity available relative to the installed capacity, and the red shading indicates the unserved energy magnitude
- In the observed events in June and July, the thermal unit availability is low due to multiple resource outages, and solar, wind, and storage resources are unable to resolve the shortfalls
- Resources with higher outage rates are more likely to have outages concurrent with loss-of-load events

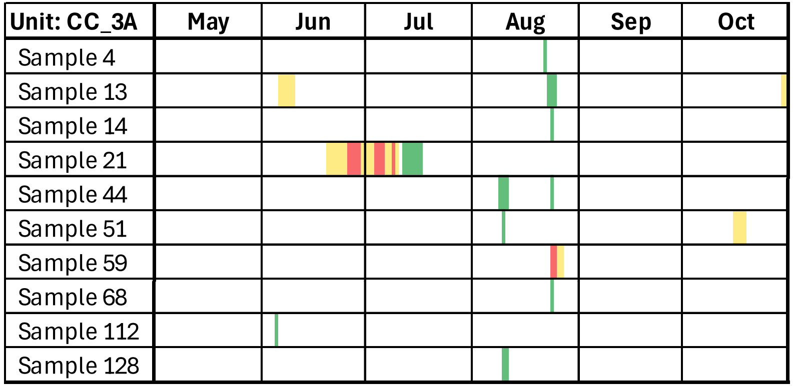


Resource Size vs. Loss-of-Load Events

- Outages of larger units are more likely to be correlated to a loss-of-load event than small units
- In the example,
  - Unit 1A: 30 MW, 2% outage rate
  - Unit 3A: 120 MW, 2% outage rate

Legend:
- White: unit is available
- Yellow: unit is out-of-service
- Green: unit is available during a loss-of-load event
- Red: unit is out-of-service during a loss-of-load event





Questions

ENERGY-LIMITED RESOURCE AND ENERGY STORAGE MODELING

ISO Proposed Modeling for Energy-Limited Resources and Energy Storage Resources

- As discussed at the November Market Committee (MC) meeting, the ISO proposes using a daily EL3 energy-limited type model to model the Oil, Jet Fuel, and Kerosene resources that have qualified storage inventories of less than 24 hours at MCap

- The ISO will propose to model batteries and pump storage hydro resources as energy storage resources – details of this proposal will be discussed starting with the December MC

Overview of Energy-Limited and Energy Storage Resources

- Daily energy-limited (EL3) resources and energy storage (ES) are both dispatchable to provide capacity only when called upon – the amount of capacity they provide for each hour depends upon how much stored energy remains, the maximum discharging capacity, and how much energy is needed to satisfy load
  - Unit dispatch is handled on a load level basis. For example, in the test model the storage resources will have 5 unique dispatches for each sample, one for each load level
- Daily EL3 resources replenish their storage from outside the system – their daily energy limit resets at midnight each day
- ES relies upon charging from the system to replenish its stored energy – charging occurs in hours when the total non-energy limited capacity is greater than the load
- The ISO proposes configuring the dispatch logic to discharge EL3 and ES resources from longest to shortest duration and charge from shortest to longest duration

EL3 and ES Unit Parameters

- Configuration includes three categories:
  - Resource capability, including discharging and charging capabilities
  - Forced outage rates
  - Discharging & charging order
- The tables for these configurations in MARS are:
  - MOD-ELMW: EL3 Capabilities
  - MOD-ESMW: ES Capabilities
  - MOD-DLAY & MOD-PRIO: Discharging & charging Order
  - UNT-FORS/UNT-TRNS: Forced outage rates
    - Forced outage modeling for ES/EL3 is identical to thermal resources

EL3 Capability Modeling

- EL3 resources are configured to have a daily limit of energy equal to their maximum discharging rating multiplied by the number of hours the unit can operate at full MCap based on their qualified inventory (inventory hours)
- This was discussed at the November MC
- Inputs are specified in the MOD-ELMW table

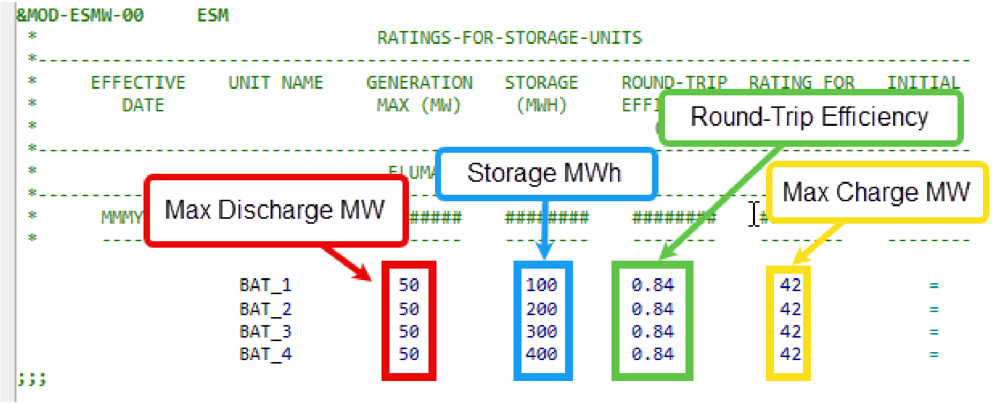
```
&MOD-ELMW-00      ELM
 *                                   RATINGS-FOR-TYPE-2-AND-TYPE-3-ENERGY-LIMITED-UNITS
 *-------------------------------------------------------------------------------------------------------------------------------
 *      EFFECTIVE     UNIT NAME      MINIMUM     MAXIMUM      ENERGY      STORAGE      DAYS     DAYS    HOURS    HOURS    HOURS      ENERGY
 *        DATE                         (MW)        (MW)       (MWH)        (MWH)       PER      PER      PER      PER      PER      PER DAY
 *                                                                                     YEAR    MONTH     YEAR    MONTH     DAY
 *-------------------------------------------------------------------------------------------------------------------------------
 *                                                 MAX.     .ELUENG.     .EL2STR.  .IEL2MD..IEL2MD                               .EE12DH.
 *------------------------                                                                                                  -----------
 *       MMMYYYY      AAAAAAAA      ########    ########    ########     ########     III      III     IIII      III      III      ######
 *       -------      --------      --------    --------    --------     --------     ---      ---     ----      ---      ---      ------

                      PROXY_EL             0         100           =            0       =        =        =        =        =        1200
```

Max Dispatch MW → 100
Total Daily Energy → 1200

- All EL3 storage is reset to 100% at midnight each day

ES Capability Modeling

- Energy storage resources are modeled with a maximum discharging rating, charge rating, round-trip efficiency (RTE), and total storage capacity
  - Charge rating is equal to discharge rating by default if not specified
- Inputs are specified in the MOD-ESMW table



- At the start of each iteration of a simulation run, each ES unit starts with 100% of its storage capacity.

Modeling Forced Outages

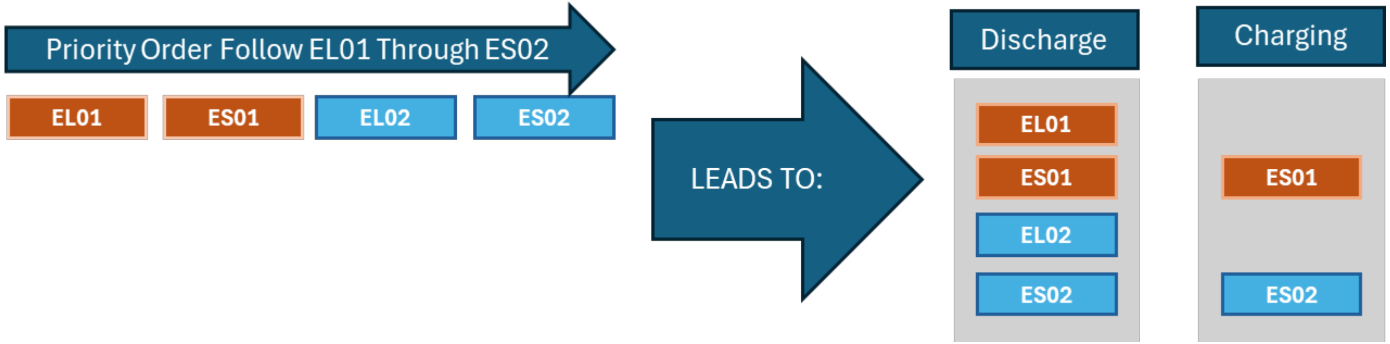
- EL3 and pumped-storage resources are modeled using the outage data reported in GADS
- MARS simulates the forced outages for EL3 and ES the same way as for thermal units
  - When simulated to be out of service, the resource does not provide capacity, but stored energy amount is maintained
  - ES does not charge if out of service as well

Proposed Discharging and Charging Logics

- As discussed at the November MC, the ISO proposes to discharge EL3 and ES resources in the order from the longest duration to the shortest duration and to charge in the order from the shortest duration to the longest duration
- The discharge order is implemented by assigning resources to different discharging groups, with the longest duration assigned to the first group for discharging, while the shortest duration is assigned to the last group
- The charging order is specified in a Priority Order list, with the shortest duration placed first to charge, and the longest duration placed last
  - Resources with the same duration will not be charged proportionally, but will follow the order on the list
- The following two slides will explain how discharging and charging are handled differently

MARS Priority Orders for Discharging and Charging

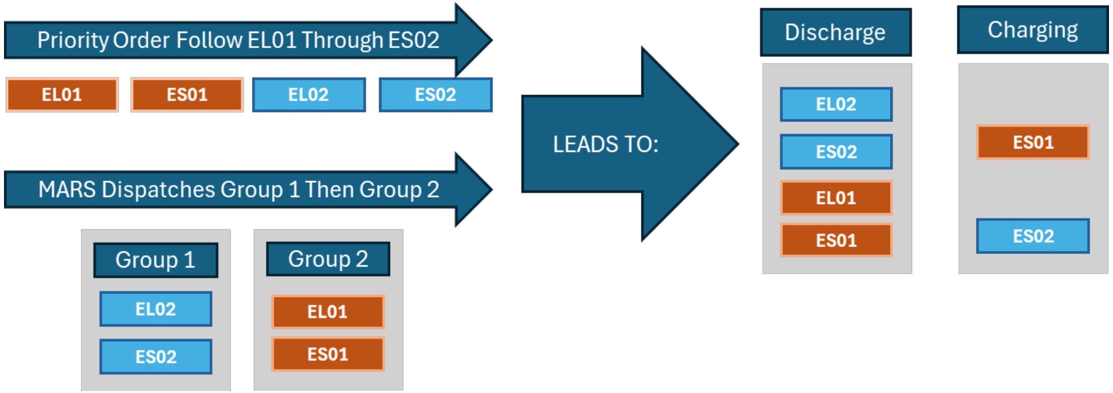
- MOD-PRIO defines the specific dispatch order for energy-limited resources (including EL3 and energy-storage)
- In the example below, resources are ordered so that daily energy-limited resources EL01 and EL02 are dispatched before the energy storage resources of similar duration ES01 and ES02
- When MARS dispatches energy-storage resources to charge, the daily energy-limited resources (EL01 and EL02) will be ignored.



- To achieve the dispatch logic that is proposed, the discharging groups is used under MOD-DLAY to control discharge order

MARS Discharging Groups

- MOD-DLAY allows the grouping of resources in an order that modifies the order in MOD-PRIO for discharging. Group 1 units are discharged first, Group 99 units are discharged last, regardless of the order in MOD-PRIO



- Grouping the 2-hour resources in discharge group 1 and 1-hour resources in group 2 tells MARS to dispatch EL02 and ES02 before EL01 and ES01 for discharging energy
- The Priority Order then tells MARS to dispatch EL02 before ES02, then EL01 before ES01
- Charging does not consider dispatch groups, so the Priority Order tells MARS to charge ES01 before ES02

Example 1: One EL3 and One ES

- Oil1 is a 100 MW EL3 resource with a 400 MWh daily energy limit
- ES02 is a 100 MW ES Resource with 200 MWh of storage capacity
- EL3 and ES are only used when other capacity is not sufficient
- Oil1 was discharged before ES02, as it has a longer duration

Hour	Load	Other Capacity	Oil1	ES02	Total Capacity	Unserved Energy
1	1,000 MW	800 MW	100 MW	100 MW	1,000 MW	0 MW
2	1,100MW	900 MW	100 MW	100 MW	1,100 MW	0 MW
3	1,100MW	1,000 MW	100 MW	0 MW	1,100 MW	0 MW
4	1,000 MW	1,000 MW	0 MW	0 MW	1,000 MW	0 MW
5	1,100 MW	900 MW	100 MW	0 MW	1,000 MW	100 MW

Example 2: Dispatch of ES and EL3 Resources Respect the Stored Energy Constraint

- MARS tracks each resource's state of charge (SoC) and uses it as a constraint for the amount of energy available to provide in each interval prior to discharge and charging

Hour	Pre-Storage Margin	Oil1		ES02		Unserved Energy
		SoC	Dispatch	SoC	Dispatch	
1	-200 MW	*400 MWh*	100 MW	*200 MWh*	100 MW	0 MW
2	-200 MW	*300 MWh*	100 MW	*100 MWh*	100 MW	0 MW
3	-100 MW	*200 MWh*	100 MW	*0 MWh*	0 MW	0 MW
4	0MW	*100 MWh*	0 MW	*0 MWh*	0 MW	0 MW
5	-200 MW	*100 MWh*	100 MW	*0 MWh*	0 MW	100 MW

- The column "Pre-Storage Margin" is the difference between load and total capacity provided by non-energy-limited resources. The negative value represents the total capacity needed from ES and EL3

Example 3: When Non-Energy-Limited Capacity Exceeds Demand, Energy Storage Resources can Charge

- Starting with example 1, but the non-energy-limited capacity is 200 MW higher in hour 3
- ES02 is assumed to have an RTE of 100%
- Because load is satisfied by non-energy limited capacity, Oil1 is not dispatched to provide capacity in hour 3
- Non-energy-limited capacity exceeds the load by 100 MW, ES02 is dispatched to charge 100 MW in hour 3

Hour	Load	Other Capacity	Oil1	ES02	Total Capacity	Unserved Energy
1	1,000 MW	800MW	100 MW	100 MW	1,000 MW	0 MW
2	1,100MW	900 MW	100 MW	100 MW	1,100 MW	0 MW
3	1,100MW	1,000 MW + 200MW	0 MW	-100 MW	1,100 MW	0 MW
4	1,000 MW	1,000 MW	0 MW	0 MW	1,000 MW	0 MW
5	1,100 MW	900 MW	100 MW	100 MW	1,100 MW	0 MW

Example 4: Charging Energy Storage Resources Adds Energy Back into Storage

- Oil1's state of charge does not change between hour 3 and hour 4 because the unit is not dispatched in hour 3
- ES02 continues to assume an RTE of 100%
- ES02's state of charge increases to 100 MWh for hour 4 because MARS dispatches the resource for charging in hour 3

Hour	Pre-Storage Margin	Oil1		ES02		Unserved Energy
		SoC	Dispatch	SoC	Dispatch	
1	-200 MW	*400 MWh*	100 MW	*200 MWh*	100 MW	0 MW
2	-200 MW	*300 MWh*	100 MW	*100 MWh*	100 MW	0 MW
3	100 MW	*200 MWh*	0 MW	*0 MWh*	-100 MW	0 MW
4	0 MW	*200 MWh*	0 MW	*100 MWh*	0 MW	0 MW
5	-200 MW	*200 MWh*	100 MW	*100 MWh*	100 MW	0 MW

Example 5: EL3 and ES Only Discharge Up to Actual Need

- MARS dispatches EL3 and ES resources until either (a) the load is met or (b) all energy available has been utilized
- Starting with Example 1, non-energy-limited capacity is then increased by 50MW in hour 2
- In hour 2, the system needs 50 MW less from EL3 and ES resources, meaning ES02 is now dispatched for 50 MW instead of 100 MW
- In hour 5, ES02 now has 50 MWh in storage and is dispatched to cover load, reducing load shed from 100 MW to 50 MW

Hour	Load	Other Capacity	Oil1	ES02	Total Capacity	Unserved Energy
1	1,000 MW	800MW	100 MW	100 MW	1,000 MW	0 MW
2	1,100MW	900 MW + 50MW	100 MW	100 MW - 50MW	1,100 MW	0 MW
3	1,100MW	1,000 MW	100 MW	0 MW	1,100 MW	0 MW
4	1,000 MW	1,000 MW	0 MW	0 MW	1,000 MW	0 MW
5	1,100 MW	900 MW	100 MW	0 MW + 50 MW	1,000 MW + 50 MW	50 MW

Example 6: Round-Trip Efficiency Affects the Amount of Energy Stored When Charging

- Consider Example 4, where ES02's RTE is no longer 100% and instead decreases to 84%
- Similar to Example 4, ES02 is dispatched to charge in hour 3, and the available energy allows it to charge at 100 MW for one hour
- With an RTE of 84%, only 84 MWh is stored for use in a future interval; the other 16 MWh of energy are system losses
- In hour 5, ES02 is dispatched to provide capacity equal to its energy in storage – 84 MW – and hour 5 realizes 16 MW of load shed

Hour	Pre-Storage Margin	Oil1		ES02		Unserved Energy
		SoC	Dispatch	SoC	Dispatch	
1	-200 MW	*400 MWh*	100 MW	*200 MWh*	100 MW	0 MW
2	-200 MW	*300 MWh*	100 MW	*100 MWh*	100 MW	0 MW
3	100 MW	*200 MWh*	0 MW	*0 MWh*	-100 MW	0 MW
4	0 MW	*200 MWh*	0 MW	*84 MWh*	0 MW	0 MW
5	-200 MW	*200 MWh*	100 MW	*84 MWh*	84 MW	16 MW

Example 7: Discharging and Charging Multiple ES Units

- MARS simulations are configured to discharge daily energy-limited and energy storage resources, from longest duration to shortest duration, then charge from the shortest duration to the longest duration
- ES02 is a 2-hour, 100 MW ES resource with 84% RTE
- ES01 is a 1-hour, 50 MW ES resource with 84% RTE

Hour	Pre-Storage Margin	Oil1		ES02		ES01		Unserved Energy
		SoC	Dispatch	SoC	Dispatch	SoC2	Dispatch	
1	-200 MW	*400 MWh*	100 MW	*200 MWh*	100 MW	*50 MWh*	0MW	0 MW
2	-250 MW	*300 MWh*	100 MW	*100 MWh*	100 MW	*50 MWh*	50 MW	0 MW
3	100 MW	*200 MWh*	0 MW	*0 MWh*	-50 MW	*0 MWh*	-50 MW	0 MW
4	0 MW	*200 MWh*	0 MW	*42 MWh*	0 MW	*42 MWh*	0 MW	0 MW
5	-200 MW	*200 MWh*	100 MW	*42 MWh*	42 MW	*42 MWh*	42 MW	16 MW

Questions

LOAD AND PROFILE RESOURCES MODELING

Updated Load Model to Integrate New Load Forecast Methodology Introduced in 2025 CELT

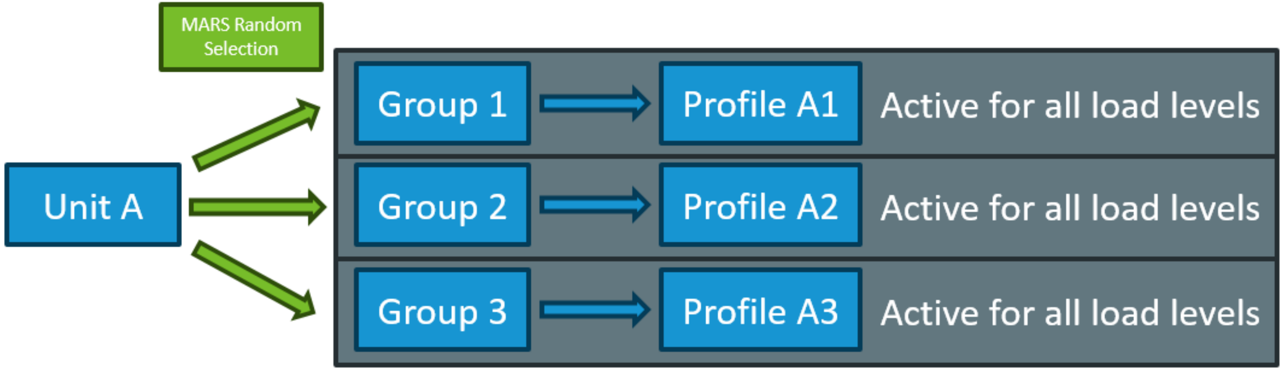
- Load model is now based on 70 years of historical weather
- A subset of these weather years is directly modeled in MARS to capture the distribution of the peak load from the updated CELT load model
  - 16 years are modeled for the summer (between 2007 and 2023)
  - 14 years are modeled for the winter (between 2000/01 and 2022/23)
- Each load shape is modeled as a load level
  - In MARS, load levels can be defined with their respective probability of occurring
  - For every replication, all of the load levels are simulated, and the expected outcome is the weighted average across the load levels
  - If you have 10 load levels and run 1,000 replications, MARS will simulate the study year 10,000 times

Intermittent Power Resources (IPR) Modeling

- IPRs are modeled as hourly modifier units with input hourly profiles
- In MARS, hourly modifier units can have
  - A single hourly profile that is used for every replication and load level
  - Multiple hourly profiles, which are randomly selected for each replication
  - Specifications on if such profile is correlated with load
- The following slides will illustrate in a simplified example how to model IPRs whose profiles are correlated with load vs. uncorrelated with load
  - There are three load weather years modeled
  - Unit A has three hourly profiles that are not correlated with load years
  - Unit B has three hourly profiles that are correlated with the load years (e.g., solar is being modeled in the summer)

IPR Uncorrelated with Load (Random Selections)

- In this case, Unit A can be defined as having three profiles that are assigned to three groups
- For each MARS replication, one of these three Groups is randomly selected
- If Group 1 is selected, Profile A1 is applied to Unit A for that replication
- Unit A is not set to be only active for a specific load level, so this selection applies to all load levels



IPR Uncorrelated with Load - MARS Tables

- MOD-RAND-00 defines the random groups along with their probabilities

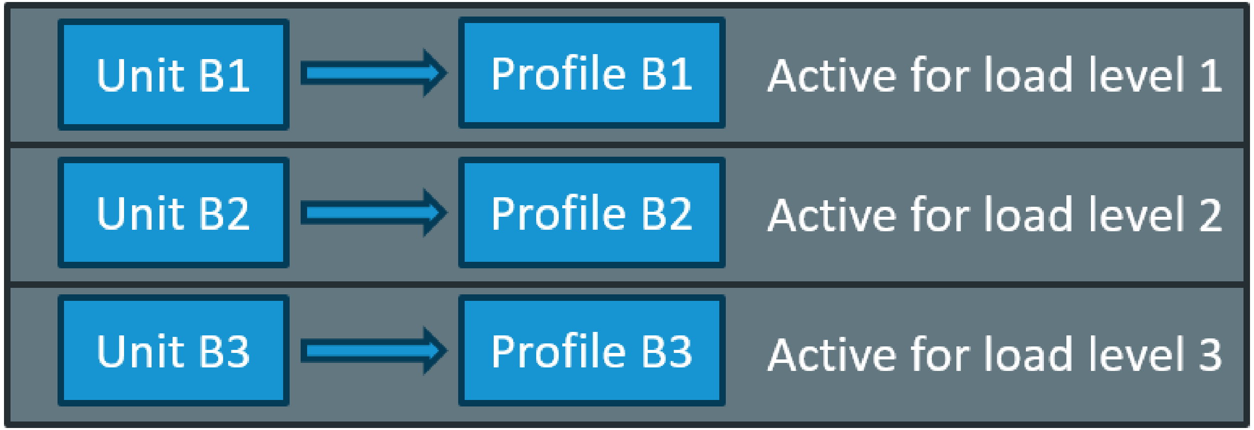
```
&MOD-RAND-00     MRD       CONTINUATUIN
*           HOURLY MODIFER RANDOM DRAW
*-----------------------------------------------
*    RANDOM GROUP        SET         P.U. OF
*      NUMBER            NAME       RANDOM DRAW
*-----------------------------------------------
*       III            AAAAAAAA          #
*       ---            --------       -------

         1             GROUP_1        0.33
+                      GROUP_2        0.33
+                      GROUP_3        0.34

;;;; END OF &MOD-RAND-00 ;;;;
```

- MOD-SHAP-03 links the three profiles to the random group
  - When MARS selects GROUP_1 for a replication, SHAP_A1 is used for UNIT_A

```
&MOD-SHAP-03      MS3         CONTINUATION
*                                HOURLY-PROFILE-SHAPE-RELATION
*-------------------------------------------------------------------------
*                   GROUP NUMBER   MAX. NUMBER   SET NAME
*                    FOR RANDOM     OF DAYS     FOR RANDOM
*    UNIT NAME       SELECTION     FOR SHIFT       DRAW
*-------------------------------------------------------------------------
*                     .IMDGRP.      .MDSHFT.
*-------------------------------------------------------------------------
*    AAAAAAAA           III            III       AAAAAAAA      AAAAAAAA
*    --------           ---            ---       --------      --------

     UNIT_A              1              =         GROUP_1       SHAP_A1
     UNIT_A              1              =         GROUP_2       SHAP_A2
     UNIT_A              1              =         GROUP_3       SHAP_A3

 ;;;; END OF &MOD-SHAP-03 ;;;;
```

IPR Correlated with Load

- In this case, Unit B needs to be defined as three units: Unit B1, Unit B2, and Unit B3, each having one profile associated with it
- Each unit is set to be active only for the load level its profile is correlated with and inactive for the other two load levels
- For every replication, Unit B1 will have its Profile B1 active only for load level 1



IPR Correlated with Load - MARS Tables

- MOD-SHAP-03 applies the three profiles (SHAP_B1, SHAP_B2, and SHAP_B3) to the three units (UNIT_B1, UNIT_B2, and UNIT_B3)

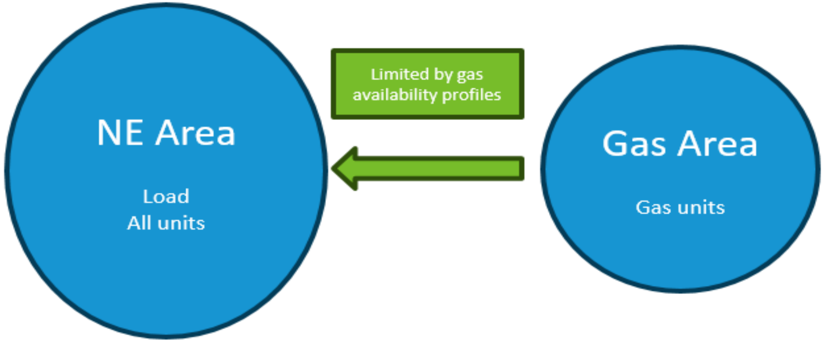
```
&MOD-SHAP-03      MS3         CONTINUATION
*                                      HOURLY-PROFILE-SHAPE-RELATION
*------------------------------------------------------------------------------
*                          GROUP NUMBER    MAX. NUMBER    SET NAME
*                           FOR RANDOM       OF DAYS     FOR RANDOM
*    UNIT NAME              SELECTION       FOR SHIFT       DRAW
*------------------------------------------------------------------------------
*                              .IMDGRP.        .MDSHFT.
*------------------------------------------------------------------------------
*    AAAAAAAA                  III             III         AAAAAAAA      AAAAAAAA
*    --------                  ---             ---         --------      --------

     UNIT_B1                   0               =              =          SHAP_B1
     UNIT_B2                   0               =              =          SHAP_B2
     UNIT_B3                   0               =              =          SHAP_B3

;;;; END OF &MOD-SHAP-03 ;;;;
```

- MOD-UNCY-01 toggles the three units to be active or inactive for each load level

```
&MOD-UNCY-01      MU1      CONTINUATION
*                     NON-THERMAL-UNITS-AND-LOAD-LEVELS
*------------------------------------------------------------------------------
*     EFFECTIVE     UNIT NAME       APPLY    UNIT AVAILABILITY BY LOAD
*       DATE                         LFU                LEVEL
*------------------------------------------------------------------------------
*      MMMYYYY      AAAAAAAA         Y/N     Y/N    Y/N    Y/N    Y/N
*      -------      --------         ---     ---    ---    ---    ---

                    UNIT_B1           N       Y      N      N
                    UNIT_B2           N       N      Y      N
                    UNIT_B3           N       N      N      Y

;;;; END OF MOD-UNCY-01 ;;;;
```

Modeling Gas Supply Constraints Using Availability Profiles

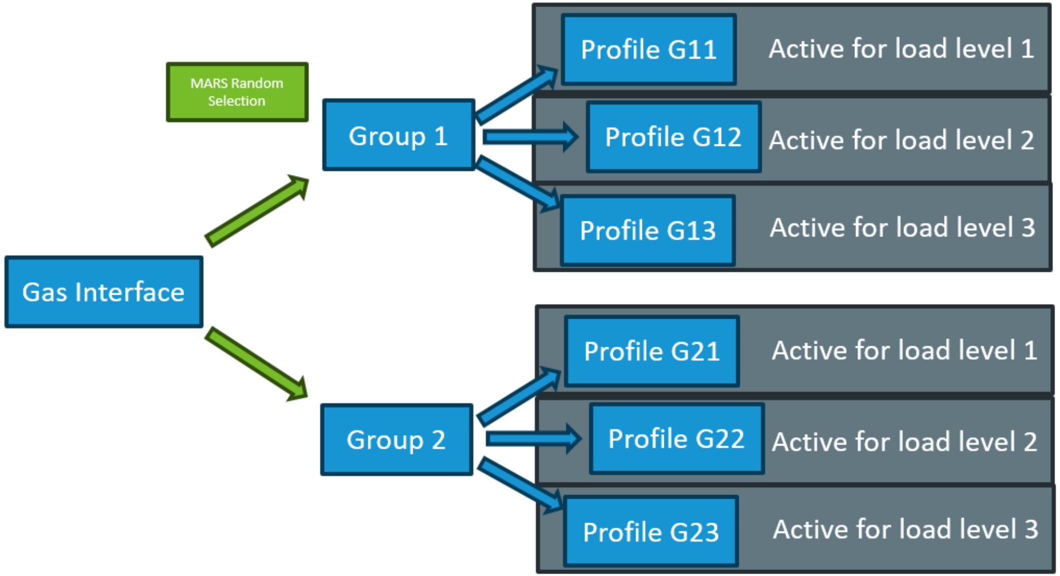
- Hourly gas availability profiles are used to represent the total amount of gas generation that the available gas supply can support for each hour in the winter
- All gas units are placed in a gas export area, which is connected to our main MARS area through an export interface
  - There is no load in the gas export area
  - The interface limit can be set to change on an hourly basis in accordance with the hourly gas availability profiles using a new MARS feature recently developed, similar to how hourly profiles are applied to units to model IPRs



Stochastic Gas Availability Modeling

- The ISO proposes using a stochastic model to represent the uncertainty in gas availability and its correlation with load
- For each load level (load year), there are multiple gas availability profiles, each assigned a probability that will be randomly selected by MARS when assessing that load year

Illustrative example showing the mapping of three modeled load years, each with two gas availability profiles associated with it



Stochastic Gas Availability Modeling - MARS Tables

- MOD-RAND-00 defines the two random groups and their probabilities

- INF-SHAP-00 assigns the shapes to their respective random group and load level

```
&MOD-RAND-00      MRD       CONTINUATUIN
*             HOURLY MODIFER RANDOM DRAW
*-------------------------------------------------------
*     RANDOM GROUP        SET          P.U. OF
*       NUMBER            NAME        RANDOM DRAW
*-------------------------------------------------------
*         III           AAAAAAAA          #
*         ---           ---------      --------

           1            GAS_1        0.75
+                       GAS_2        0.25

;;;; END OF &MOD-RAND-00 ;;;;
```

```
&INF-SHAP-00      ISH      CONTINUATION
*                               INTERFACE LIMIT SHAPES
*-----------------------------------------------------------------------------------------------
*       INTERFACE      POSITIVE     LOAD LEVEL    SET NAME FOR   SHAPE NAMES     PENETRATION
*          OR             OR                       RANDOM DRAW                     FACTORS
*       INTERFACE      NEGATIVE
*         GROUP        DIRECTION
*          NAME
*-----------------------------------------------------------------------------------------------
*                                                                 .SHMDNM.        .SHMDPN.
*-----------------------------------------------------------------------------------------------
*        AAAAAAAA        P/N          III          AAAAAAAA       AAAAAAAA        ########
*        --------        ---          --           --------       --------        --------

         GAS_2_NE         P            1            GAS_1          SHAP_11          1.0
+                                      2            GAS_1          SHAP_12          1.0
+                                      3            GAS_1          SHAP_13          1.0
+                                      1            GAS_2          SHAP_21          1.0
+                                      2            GAS_2          SHAP_22          1.0
+                                      3            GAS_2          SHAP_23          1.0

;;;; END OF INF-SHAP-00 ;;;;
```

Questions