Edison Electric INSTITUTE



High-Energy Control Assessments (HECA)

Principal Authors:

Dr. Matthew Hallowell
Dr. Elif Deniz Oguz Erkal

September 2024

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Dr. Matthew Hallowell
Dr. Elif Deniz Oguz Erkal

Prepared for:
Edison Electric Institute

September 2024

Printed in the United States of America.

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Contact

Carren Spencer
Director, Safety & Health Policy
(202) 508-5166
cspencer@eei.org

Executive Summary

High-Energy Control Assessments (HECA) is a new method of measuring performance by assessing the extent to which front-line employees are adequately protected against life-threatening hazards. Specifically, HECA is computed as the percentage of high-energy hazards that have a corresponding Direct Control. By applying precise definitions of 'high-energy' and 'Direct Control,' we can ensure that HECA is consistently measured within and across companies. HECA information is designed to be collected during typical site visits by observing work conditions and engaging with front-line employees (i.e., Energy-Based Observations (EBOs)).

HECA may be assessed by following three steps while performing an observation.

- Step 1: Identify all high-energy hazards during an EBO. When the energy associated with a hazard exceeds 500 ft-lbs, the most likely outcome is a serious injury or fatality (SIF) if contacted. Therefore, high-energy hazards can be considered life-threatening hazards or the "stuff that kills you" (STKY).
- Step 2: Assess the presence or absence of Direct Controls. For each of the high-energy hazards identified, mark which have a corresponding Direct Control at the time of initial observation. To be a Direct Control, a safeguard must meet all the following criteria:
  a. Specifically targeted to the high-energy source;
  b. Effectively mitigates exposure to high energy when installed, verified, and used properly; and
  c. Effective even when someone makes a mistake.
- Step 3: Compute the HECA Score. Apply the equation below to determine the proportion of high-energy hazards that had a corresponding Direct Control at the time of observation.

$$\boldsymbol{HECA} = \frac{\boldsymbol{Success}}{(\boldsymbol{Success} + \boldsymbol{Exposure})}$$

Success: total number of high-energy hazards with a corresponding Direct Control
Exposure total number of high-energy hazards without a corresponding Direct Control

Please refer to 'The Rulebook' section of this report for details on consistent data capture and scoping (i.e., sampling strategy, training etc.).

HECA is a transformative new metric because it:

- Is based on the understanding that "safety" is the presence of safeguards;
- Marries science of energy-based safety with the principles of human and organizational performance (HOP);
- Is based on the understanding that even the best employees make mistakes, so our controls against life-threatening hazards must be effective even when someone makes a mistake;
- Specifically focuses on prevention of SIFs by measuring and addressing SIF-related conditions;
- Supports regular, sustained learning from both success and exposure;
- Enables organizations to measure and learn from normal work in real-time through continuous monitoring; and

- Provides qualitative and quantitative information on SIF risks to allow for targeted intervention and safety investments.

Tracking and learning from HECA could redirect attention from lower-severity incidents to conditions that have the potential to be life-threatening or life-altering, which would be an important step toward the elimination of SIFs. If HECA is applied consistently across companies, it has the potential to support shared learning and benchmarking. This report serves as a governance document to ensure that the Edison Electric Institute (EEI) community has one definition of HECA and a set of rules and sampling procedures to follow.

Motivation

SIFs remain a persistent challenge across various industrial sectors. While the electric power generation and delivery sector has observed a consistent decline in recordable injuries over the past decade, the rates of SIFs have reached a plateau, as illustrated in Figure 1. Contrary to previous theories, accumulating evidence suggests that the underlying causes of SIFs differ significantly from those of low-severity injuries. Therefore, the conventional approach of reducing the rate of low-severity injuries may not necessarily result in a corresponding reduction in SIFs. Consequently, the study of SIFs requires a distinct and specialized approach compared to incidents of lower severity.

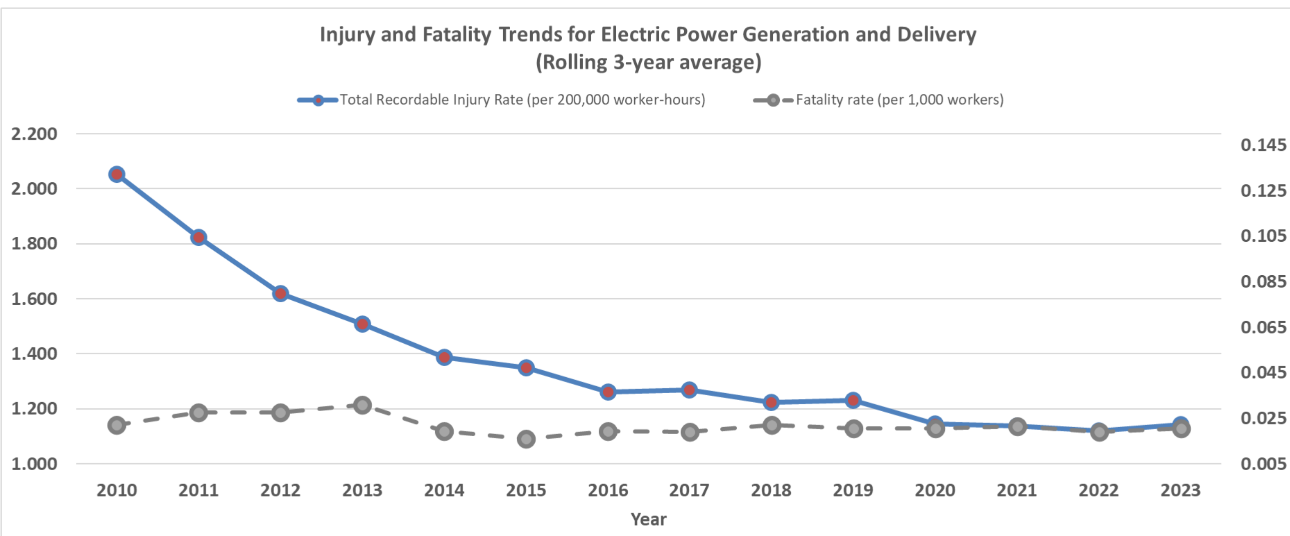


Figure 1 – Power generation and delivery recordable injury and fatality trends

The elimination of SIFs must be established as a top priority. Although theoretically attainable, achieving this goal will require extensive collaboration across the industry. From the standpoint of data availability, it's crucial to recognize that actual and potential SIFs (i.e., SIFs and PSIFs) are infrequent and extraordinary events. When examined in small sample sizes, they may not reveal any significant patterns or trends. As a result, individual organizations lack access to sufficient data for the necessary learning to effectively prevent SIFs. Therefore, new methods of regularly and more broadly monitoring SIF conditions are needed.

Motivated by the plateau in SIFs; the need for more valid, reliable, and meaningful safety SIF-related data; and a desire to collaborate, an EEI team was established to pilot, refine, and standardize a new approach to safety monitoring known as High-Energy Control Assessments (HECA). HECA was recently introduced as a method of monitoring SIF conditions through modification of existing safety observation programs. HECA focuses directly on SIF prevention by assessing the extent which life-threatening hazards are adequately controlled. Because HECA is based on the objective assessment of physical energy and the deployment of consistent definitions, HECA may be measured consistently within and across companies.

The purpose of this document is to provide a summary of HECA, establish a set of rules to ensure consistent application, provide guidance on sampling, and share insights on the intelligence that can be gained from analysis and industry-level learning teams. This report will serve as a governance document established by EEI that member companies can reference to ensure their alignment.

Overview of HECA

HECA is a method of measuring safety performance that evaluates the extent to which front-line workers are protected against life-threatening hazards. Specifically, HECA is calculated as the percentage of high-energy hazards with a corresponding Direct Control. HECA was first introduced in Oguz Erkal and Hallowell (2023) as the result of a Construction Safety Research Alliance (CSRA) project. The method leverages the assessment of high energy from Hallowell et al. (2017) and the definitions of Direct Controls in EEI's Safety Classification and Learning (SCL) Model report that first was published in 2020. (EEI 2020).

HECA was envisioned as a method of monitoring safety performance that is based on:

1. **Science of energy-based safety.** The things that hurt people are not the same as the things that kill people. Further, we know that transfer of energy to the human body causes injury. Specifically, we know that although every hazard has the remote possibility of causing a SIF, high-energy hazards are *most likely* to cause a SIF as more energy causes more harm. Therefore, by targeting high-energy hazards during an evaluation we can focus efforts on SIF prevention. This is a critical distinction and a significant departure from traditional safety management.
2. **Knowledge that SIFs are prevented when hazardous energy is adequately controlled.** Research shows that the proximal cause of SIFs is missing or inadequate control of high-energy hazards. Therefore, the key to SIF prevention is ensuring that adequate controls are in place for all operations involving high-energy. Adequate controls for high-energy hazards are described in EEI (2020) as Direct Controls.
3. **Understanding that error is normal.** In addition to targeting and controlling high energy, Direct Controls must be resilient against human error. This is based on the understanding that even top professionals make mistakes. Therefore, once installed and verified, controls against high-energy hazards are not deemed adequate if they are vulnerable to human error.
4. **Definition of safety as the presence of safeguards.** The structure of the HECA score as the proportion of high-energy hazards with a corresponding Direct Control directly reflects the modern definition of "safety as the presence of safeguards." By using basic physics for energy assessment and the operational definition of Direct Controls, HECA provides an objective method of measuring safety.

5. **Assessment of SIF conditions.** SIFs are a paradox because although they are critically important, they are exceedingly rare. Thus, despite the desire to learn and improve methods of SIF prevention, data are often too scarce to support meaningful trending and learning. Because HECA is designed to measure safety at any moment in time, it can be monitored and tracked regularly. When integrated as a part of typical safety observations, HECA can be used to assess SIF conditions any time a trained observer visits an active worksite. The ability to regularly measure safety is an important transition from measuring and responding to monitoring and controlling safety.
6. **Need for consistency.** Metrics are used for two purposes: comparing and learning. If we wish to compare company performance, we must have metrics that are applied consistently. Similarly, dataset cannot be combined and leveraged to support industry-level learning unless the data are collected according to a set of shared definitions and by strictly applying a consistent set of rules. Therefore, the EEI team developed this HECA data collection strategy that includes definitions, rules, and sampling guidelines.

How to Implement HECA

HECA was designed to integrate directly with most company's safety observation programs. Here, safety observations are defined as the process of visiting a site, engaging with employees, recording observations, and providing recommendations. A safety observation that focuses specifically on the assessment of high-energy hazards and their corresponding controls will be referred to as an 'Energy-Based Observation (EBO).' EBOs are required to collect the information necessary to compute a HECA score. Here, it is important to make the distinction that EBOs can include a variety of activities from leadership engagement to coaching related to high energy. However, a HECA is solely a register of high-energy hazards and Direct Controls observed at the beginning of the observation during ongoing work before any intervention. This register is later used to calculate HECA scores.

Computing a HECA score requires three steps. Each step requires the strict adherence to the definitions and assessment methods described. Traditional methods based on individual observer judgments are replaced with objective assessment criteria. Note that even with the definitions, a set of rules are also required to ensure that measurements are collected and reported the same across observers.

Step 1: Identify high-energy hazards

The first step in HECA is to identify all high-energy hazards faced by a specific work crew at the time of observation. The term "high-energy" is based on research that showed that the severity of an injury is directly related to the magnitude of physical energy associated with a hazard (Alexander et al., 2017). For example, a heavier object higher off the ground has more potential for serious harm than a lighter object lower to the ground. Specifically, Hallowell et al. (2017) found that hazards with less than 500 joules of energy are most likely to cause a first aid injury; hazards with between 500 and 1,500 joules of energy are most likely to cause a medical case injury; and hazards with more than 1,500 joules of physical energy are most likely to cause a serious injury or fatality (Hallowell et al., 2017). Therefore, the term 'high-energy' is used to describe hazards with more than 1,500 joules of physical energy because the most likely result of a contact between a human and this energy source is a SIF. Put simply, high-energy hazards are the life-threatening hazards or, colloquially, STKY. The data summary from Hallowell et al. (2017) is provided as Appendix 2.

High-energy was selected as a key component of HECA to encourage a focus on SIF prevention and to ground the assessment in the latest scientific knowledge. Although practitioners have often focused on discussing the worst possible outcome associated with a hazard, this can be counterproductive because a SIF is always remotely possible. Instead, it is more productive to discuss the most likely outcome associated with a hazard. Using the concept of high-energy refocuses attention on hazards that are most likely to cause a SIF.

Computing the magnitude of energy associated with an energy source is relatively simple for some energy types (e.g., gravity and motion). However, others are much more complex such as mechanical and pressure. To enable field assessments, the 13 icons in Figure 2 were created by EEI in the 2020 EEI SCL Model report. These high-energy icons represent approximately 85 percent of all high-energy hazards documented in the original study. These icons are described along with relevant references in Appendix 3.

Although the high-energy icons enable a more practical analysis, not all high-energy hazards lend themselves to icons. For example, while some dropped tools may be high energy if the tool is high and heavy enough, many dropped tool scenarios are not high energy. Therefore, computations of energy magnitude may be required for some hazards to ensure a complete assessment. To enable such assessments, an energy calculator was created (and posted publicly at EEI's powertopreventsif.com) and the underlying equations with examples are provided in Appendix 4. We recommend using the high-energy icons in Figure 2 to simplify the energy assessment process when possible; however, actual energy magnitude should be calculated when an icon does not apply.

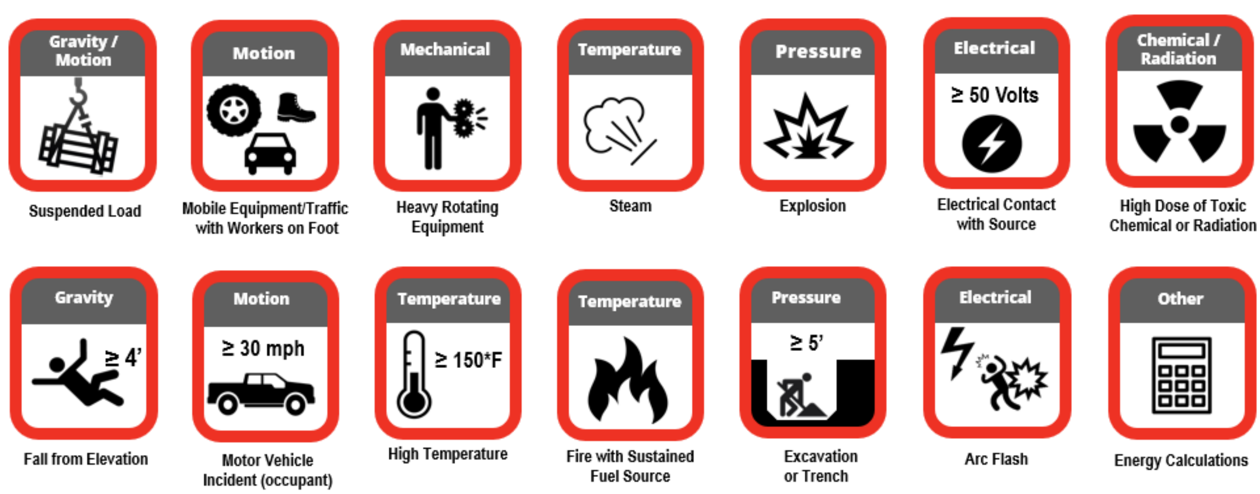


Figure 2. Example High-Energy Hazards

The following elements are not included in HECA to maintain a reasonable scope of analysis:

- Hazards related to the integrity of equipment such as electrical, engine, and hydraulic systems;
- Hypothetical or anticipated work situations;

- Exposure of the public to hazards;
- Workplace violence;
- Mental health and well-being; and
- Incidents such as actual or potential injuries or illnesses.

Although vitally important, each of the above elements were deemed out of scope for HECA, which is intended to measure safety in the moment of an actual field observation to assess the exposure of front-line employees to SIF conditions.

Step 2: Assess Direct Controls

The second step in measuring HECA involves determining if a Direct Control exists for each high-energy hazard observed. Aligning with the idea of safety as the presence of safeguards, HECA is built on the notion that every high-energy hazard should have a corresponding control that ensures that a SIF is no longer reasonably probable. Here, we use the term Direct Control to refer to a control that meets the minimum standards offered by EEI's SCL Model report. Although there are levels within the hierarchy of controls (e.g., elimination, substitution, engineering, administrative, and personal protective equipment) and different types of controls documented in literature (e.g., absolute, mitigative, and preventative), we intentionally used a definition for Direct Control that is binary (i.e., a control is or is not a Direct Control).

The SCL Model report offers a precise and strategically designed definition of a Direct Control that aligns with both energy-based safety, and human and organizational performance principles. To qualify as a Direct Control, a control must meet all three criteria of the following criteria:

- **Criteria 1: Targeted to the high-energy hazard.** The control must be specifically designed and intentionally used to address the high-energy of concern. Examples of targeted controls include fall arrest systems for work at height, machine guards for rotating equipment, and engineered excavation support systems.

- **Criteria 2: Effectively mitigates to the high-energy hazard when installed, verified, and used properly.** A Direct Control must either eliminate the energy or mitigate the energy exposure to below the 1500 Joule threshold. An example of a Direct Control that eliminates the energy exposure is the de-energization, verification, and lock-out tag-out for electrical energy. An example of a control that reduces but does not eliminate the energy is a self-retracting fall arrest system. A control is only considered present when it is installed, verified, and used properly. If the control is not installed properly, inspected on schedule, maintained regularly, or is misused, the control is considered absent. For example, a personal fall arrest system must be properly installed to an engineered anchor point, inspected, maintained on the prescribed schedule, and worn properly on the body to be considered present.

- **Criteria 3: Effective even if there is unintentional human error during the work (unrelated to the installation of the control).** Controls are not considered adequate to protect against life-threatening hazards if they require workers to be perfect when using them. Given enough time, the probability that a worker will make an unintentional error is 100 percent. Thus, it is not 'if a worker will make a mistake', it is 'when.' The controls against high-energy hazards must be functional even when someone makes a mistake during work. For example, situational awareness, signage, and training are not considered to be Direct Controls because they are all vulnerable to human error. However, engineered barricades, de-energized electrical systems, and some highly specialized personal protective equipment may be Direct Controls because they are effective even if a worker makes a mistake. Importantly, all controls are vulnerable to human error during their installation. Therefore, criterion 2 includes the language installed, verified, and used properly and criterion 3 includes the language unrelated to the installation of the control.

Note that many Direct Controls require a system of controls to be effective and that one component alone often does not constitute a Direct Control. For example, a fall protection system may require an engineered anchor point, lanyard, and a harness that is all tied to a sufficiently stable structure such as a steel frame or correctly positioned bucket truck. To be considered a Direct Control, each element must be properly designed, inspected regularly, and installed, verified, and used properly. A deficiency in any component of the system invalidates the entire Direct Control. Other examples include full coverage of flame-resistant clothing and complete isolation from electrical contact when working on live electrical lines.

Step 3: Compute the HECA Score.

Apply the equation below to determine the proportion of high-energy hazards that had a corresponding Direct Control at the time of observation. This is a simple proportion or percentage that reflect the degree to which front-line employees were adequately protected against any high-energy hazards.

$$\boldsymbol{HECA} = \frac{\boldsymbol{Success}}{(\boldsymbol{Success} + \boldsymbol{Exposure})}$$

Success: total number of high-energy hazards with a corresponding Direct Control
Exposure total number of high-energy hazards without a corresponding Direct Control

If no high-energy hazards were observed, the HECA score should not be computed, and the value (zero) should not be entered. The HECA score should always take the form of a number between 0 and 1 or represented as a percentage from zero to 100 percent. In addition to entering a HECA score, it is advisable to record which high-energy hazards were observed, which had corresponding Direct Controls, and which did not, why a control was missing (e.g., control not possible, control not available, control available and not used, etc.), and actions taken by the observer to address any exposure situations. Such data, in addition to the numerical HECA score will provide intelligence that is useful for trending and learning.

HECA Rulebook

Even with strict definitions of high-energy hazards and Direct Controls, the variability in assumptions, boundaries, and processes could lead to vast inconsistency in application and the inability to benchmark and learn across companies. Therefore, the EEI team established 10 rules of HECA implementation. These rules were subsequently tested on six real-world observation cases during three months of initial pilot testing in the field.

The ten HECA rules are as follows:

1. HECA is based on observations of active work and not the assessment or classification of an incident or the review of paperwork alone.
2. Each HECA measurement must correspond to one crew performing one task during one working day. Multiple crews and/or tasks require multiple HECA measurements.
3. If a crew performs more than one task during the observation period, a separate HECA measurement must be made for each task.
4. When two or more crews are working in proximity to one another and performing the same task, they must be grouped as one HECA measurement.
5. If two or more hazards have the same high-energy source and the same Direct Control, they must be combined as one entry.
6. If there is a deficiency or missing coverage of a Direct Control, the entry must be recorded as exposure.
7. Assessments must only be made based on work as it is observed. Hypothetical, anticipated, or speculated conditions should not be considered in the scoring.
8. One object may involve more than one high-energy hazard (e.g., a suspended load often has gravity of the lifted object and the potential lateral motion of the object).
9. Observers must make reasonable efforts to verify that Direct Controls are installed and used properly.
10. The definitions of high energy and Direct Control must be strictly applied. These definitions are explained in this report and are governed by EEI's SCL Model community of practice.

Guidance for Observing Equipment

When observing equipment, a few unique conditions required further clarification. Thus, the following are considered rules that apply specifically to heavy equipment:

- If two or more pieces of equipment working on the same task are reasonably similar, they should be counted as one entry.
- When equipment is considered part of a Direct Control, make a reasonable effort to verify that the equipment is maintained properly.
- Consider hazards related to the interaction between the equipment and the environment (e.g., equipment tracking/moving in proximity to workers on foot).
- Consider whether equipment is operating within its engineered limits (e.g., within lift capacity and boom limits, or on stable ground).
- Hazards related to the integrity of equipment such as electrical, engine, and hydraulic systems are out of scope.

It was noted that most observers who are trained in safety are not trained to assess mechanical systems in equipment. Therefore, equipment conditions (e.g., hydraulic systems) could not be assessed adequately during a normal EBO. Therefore, observers should not make assumptions about equipment adequacy and should seek guidance from employees who have sufficient knowledge.

Sampling Strategy

One of the most important questions when integrating HECA at scale is, *How many HECA entries do I need?* Fortunately, not every work condition on every day needs to be entered to have a representative understanding of the business unit. Instead, companies can rely on strategically collecting a small number of sites to gather a sample that is statistically and demographically representative of the whole.

Sampling is a statistical method used to gain meaningful insights about a large population by analyzing a smaller subset of data. For example, when we collect a large and diverse enough sample of HECA data, we can make conclusions that apply broadly to the entire organization.

Volume of data needed

Companies can estimate the number of HECA scores needed to have enough data to draw meaningful conclusions. To perform such a computation, the company must select a confidence level and estimate the total number of HECA observations possible. The confidence interval represents the probability that the conclusions drawn from the sample are actually representative of all conditions in the reporting period. The total number of HECA observations possible corresponds to an estimate of the number of crew work periods in the reporting period. Here, we consider the reporting period to be monthly, the average crew size to be 3 employees per crew, and the average number of worker-hours per crew member to be approximately 200 hours per month. Consequently, we can estimate the number of HECA observations given the number of work hours amassed per month. This is important because we have found that most companies already consistently record worker-hours monthly.

Specifically, a company can estimate the total number of HECA opportunities (i.e., a work period for one crew) by following the process and equations below:

- **Start** by estimating the total population size, represented by the total number of HECA opportunities (i.e., count of times when an assessment could be performed).
- **Consider** that each HECA is recorded for a crew performing a task.
- **Estimate** the total number of HECA opportunities by applying the equation below.

$$Number\ of\ HECA\ opportunities\ per\ month = \frac{Total\ number\ of\ field\ worker\ hours\ per\ month}{200\ hours\ per\ employee\ per\ month\ x\ 3\ employees\ per\ crew}$$

For example, if a business unit accumulated 300,000 worker hours in a month, we can use the equation above to estimate that there were 500 HECA opportunities that month.

Once the number of HECA opportunities (i.e., population size) is known, well-established statistical sampling formulas can be applied to estimate the required number of HECA entries needed. By choosing a confidence interval and making typical statistical assumptions (i.e., a 5% standard error), the sample size can be computed. Note that the confidence interval is the likelihood that the trends observed in the sample represent the actual trends in the entire organization. The higher the interval, the more confident we are that the trends are representative and meaningful.

$$\text{Sample Size Formula} = \frac{[z^2 * p(1-p)] / e^2}{1 + [z^2 * p(1-p)] / e^2 * N]}$$

Where z is Z-score (calculated from confidence interval and distribution integrals), p is the population proportion, e is the margin of error, and N is the total population size.

For example, if a business unit accumulates 300,000 worker hours per month and would like to measure their HECA score with 85 percent confidence and 5 percent marginal error, a minimum of 147 HECA entries must be collected per month, requiring an average of 5 HECA entries per day. For more accurate sampling results, the data should be collected to mirror the whole and include a balanced mix of locations, tasks, crews, etc.

To simplify the process of determining the required sample size for HECA, the table in Appendix 5 was created. This table includes sample size estimates for worker hour periods from 10,000 worker hours to 500,000 worker hours.

Ensuring representative data

The extent to which HECA data reflect the work depends both on the quality and the quantity of data. Companies should have a sample that is as close to random as possible. Over-representation of certain geographical regions, business units, crew types, or work types will skew the data. Similarly, under-representation would cause omissions and the resultant generalizations will miss such information.

The following best practices help to ensure a high-quality sample:

- **Calibrated assessors:** It is crucial that the those measuring HECA are adequately trained to follow the HECA rulebook and yield valid and reliable assessments.
- **Randomization:** Samples should be chosen without bias, ensuring each crew has an equal chance of being selected for HECA in a given work period.
- **Representativeness:** The sample should include some representation of the different types of work performed by the business unit (e.g., tasks, locations, work environments, etc.). With pure randomization or due to the convenience of the data collector, it is possible that some segments of the company are more represented than others. This would cause the generalizations to be biased towards over-represented segments. To prevent this from happening, the sampling strategy should identify the different tasks, locations, work environments, and crew types of interest that need to be represented in the sample, and control for their existence or absence in collected samples. This type of control will allow assessors to evaluate resultant HECA scores accurately.
- **Consistent cadence:** Consistent and reliable measurements with a set cadence are essential for valid results. HECA's primary mission is to facilitate continuous monitoring of SIF conditions which could only be possible with measurements that are on a short cadence. Even though HECA evaluations may be reported monthly or even quarterly, daily cadence is crucial to facilitate randomization and allow for constant monitoring.

For example, Company A that wishes to collect consistent HECA scores performs 3 different main tasks in five locations. For calibrated assessors, Company A trains and calibrates a group of safety professionals to collect HECA information the same way. Every week, the assessors are randomly assigned to different locations, different tasks, and different crews. To prevent overrepresentation, assessors are advised to avoid observing the same crew doing the same task at the same location.

Potential Risks

Although still a work in progress, the EEI team conducted an ethical hacking experiment where they attempted to identify key risks such as improper sampling, data manipulation, and ignoring rules that would severely compromise the quality of the community's HECA data. As the team deliberated, the technical advisors devised a series of proposed countermeasures such as the sampling strategy, rulebook, calibration, data quality reviews, and inter-organization validation.

Potential Risk	**Cause**	**Proposed Countermeasure**
Overestimation of HECA scores	Cherry picking best crews/tasks to achieve a desired HECA score or corporate HECA targets.	Reject HECA scores that are over 90 percent for more than 5 percent of monthly data
Analysis of a sample that is not representative of the business unit	Convenience sampling and limited resources.	Plan and randomize target observation locations, task types, crew types, etc.
Inconsistent HECA scores	Data collection pressure or convenience sampling.	Certify and re-certify HECA data collectors and conduct regular calibration sessions.
Invalid HECA scores	Poor training, calibration, and validation.	Regularly calibrate HECA assessors and conduct independent validation tests with peer utilities or verified third party organizations.
Pencil-whipping	Pressure to meet a quota.	Create reasonable HECA reporting goals that are spread over long periods.
Inclusion of low-energy tasks	Calibration or data entry issues.	Remove work tasks or observations that do not have at least one high-energy hazard.
Duplicate observations	Data entry issues or quotas.	Use duplicate entries for calibration or validation, but do not allow duplicate entries in overall composite scores.
Data included that do not represent the business unit	Inconsistent data collection.	Do not pool contractor data, exposure of the public, or other outside entities in the analysis of the business unit data.

Lessons Learned

During initial implementation of HECA, we learned a few key lessons. Since HECA is new and the EEI community will be adjusting its approach to HECA over the coming years, new lessons will be added annually in lieu of conclusions.

It is critically important to maintain one definition of HECA. One of the reasons that Total Recordable Incident Rate (TRIR) has been so pervasive is that there is only one government-mandated definition of a recordable injury. We must replicate this strength by creating and maintaining one definition of HECA. If organizations begin adapting HECA to meet their individual desires, HECA loses much of its usefulness for shared learning. Shared learning is critical for SIF elimination because no one company is going to figure out how to eliminate fatalities on their own. Instead, we must learn and advance together, which is going to require a shared vocabulary and assessment structure. Importantly, a shared vocabulary is also the underpinning of any emerging scientific field.

HECA should be used for learning and improving rather than measuring and comparing. Any metric used to compare businesses, business units, projects, teams, etc., has the potential to directly or indirectly be incentivized. HECA is no exception. When incentivized, any metric can encourage poor behavior such as underreporting, misreporting, case management, and other forms of data manipulation. The problem is not with the structure of the metric, it is with the incentives created by the organization and external stakeholders such as investors. To ensure that HECA has the greatest positive impact, it should be for continuous safety monitoring, learning, and strategic allocation of resources.

HECA can be integrated with existing processes. Most companies have observation programs where safety professionals and front-line leaders visit worksites, observe conditions, and engage with employees. HECA is strategically designed to be integrated directly with these existing activities. Although observers should focus on high-energy and Direct Controls to collect HECA data (i.e., an Energy-Based Observation), new processes are not needed to integrate HECA in most mature safety systems.

HECA data collection strategy, planning, execution, and analysis will take time. As different companies start to revise their safety performance metrics, they set aggressive goals towards HECA implementation and utilization. However, companies on this journey quickly realize that while HECA concepts are easily comprehensible, a full-scale, consistent, and continuous implementation takes time due to data collector training and calibration, generation and implementation of data collection tools, resource planning and prioritization of safety tasks, and executive education and management communication. The companies are recommended to come up with a strategic rollout plan that fits their safety culture, allows for soak time, and provides plenty of piloting opportunities to support their learning curve. Companies should acknowledge that it is normal to have inconsistent or erroneous data during the early stages of HECA data collection.

Calibration and validation are critical. As individuals begin using HECA, we found that assessments can be highly variable. This is the result of natural and unintended deviations based on assumptions and general approaches (e.g., identifying which hazards are relevant and which are not). We found that assessments converge quickly when companies lead calibration exercises where a group reviews the same situation, develops a common understanding to avoid persona assumptions, and applies the definitions and rulebook. Calibration efforts ensure that assessors in the same organization score and enter HECA consistently. Likewise, validation efforts such as a representative from one electric company visiting another (and vice versa) can help companies ensure that they are assessing HECA consistently with their peers and deem whether it is appropriate for a company to have their data aggregated or not. Validation efforts are not yet underway and may be designed as part of ongoing HECA development and governance.

The relationship among leading, lagging, and monitoring variables (e.g., HECA) should be empirically explored. Metrics are only useful if they tell a story that enables better discussions that yield more effective decisions. By understanding the potential relationships among leading indicators (inputs), HECA (system monitoring), and lagging indicators (outputs), we may see a future where collective metrics suggest what to change and by how much, what we will see in the field, and what to expect for long-term outcomes. As a system monitoring variable, HECA would play an important role in regular surveillance and control and is predictive in nature (Oguz Erkal et al. 2024).

Although HECA still needs work, it is an important step toward a future where safety metrics are aligned with safety principles. The safety community has made strides through concepts of human and organizational performance, but primary safety metrics (e.g., TRIR) remain antithetical and antiquated. HECA offers a new, intentionally designed method of assessing safety performance that is aligned with current safety principles and that may enable continuous monitoring and strategic decision making. More work is needed to understand HECA in practice, such as sampling frequency, independent validation, and prevention of manipulation, which will be the subject of future papers.

APPENDIX 1 - GLOSSARY

Crew: One or more workers assigned to complete a task.

Direct Control: A barrier that is specifically targeted to the high-energy source; effectively mitigates exposure to the high-energy source when installed, verified, and used properly; and is effective even if there is unintentional human error during work that is unrelated to the installation of the control.

Energy-Based Observation (EBO): A site visit focused on identifying high-energy hazards and assessing Direct Controls. One EBO can result in multiple HECA scores when tasks or crews change during the observation period.

Equipment: Large mechanical tools or vehicles that are used by the crew to perform a task that exceed the size and complexity of typical unpowered hand tools. Equipment examples include bucket trucks, excavators, forklifts, trenching machines, and compactors.

Exposure: Condition where high energy is present in the absence of a Direct Control.

Field Visit: The process of visiting a work site, observing conditions, and engaging with the workers.

High Energy: A hazard that exceeds 500 foot-pounds of physical energy and is most likely to cause a SIF if an employee contacts the energy.

High-Energy Control Assessment (HECA) Score: The percentage of high-energy hazards with a corresponding Direct Control.

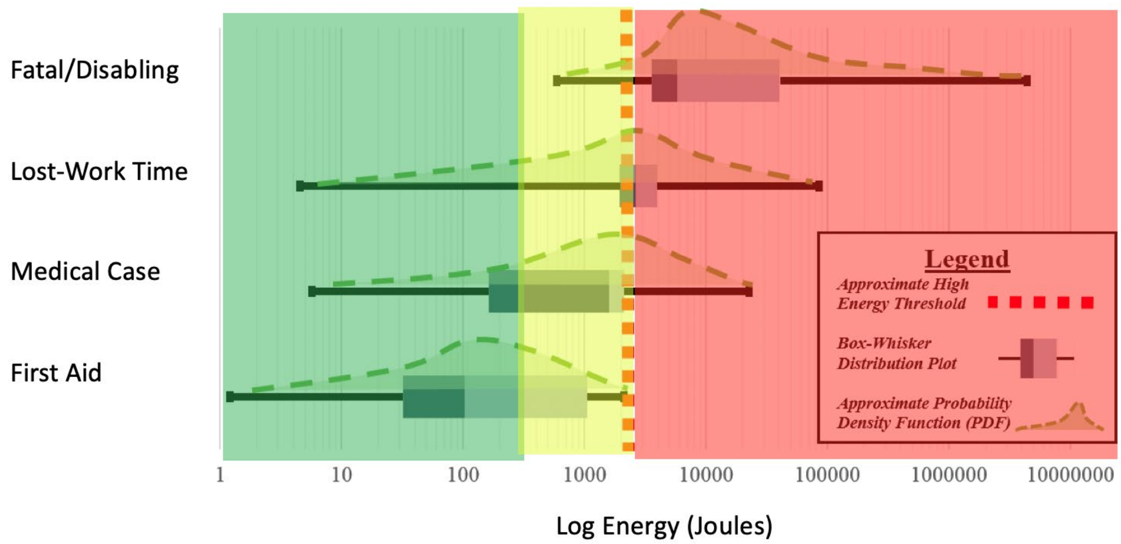
Visual Proximity: Condition where workers, hazards, or tasks are within line of sight of each other.

Relevant Hazard: A proximal hazard where there is a reasonable possibility that workers could interact with the hazard.

Success: Condition where a high energy incident does not occur because of the presence of a Direct Control.

Task: A scope of work that must be completed in a specific location and within a specified time. Tasks are distinguished by changes in materials, equipment, tools, location, or the competency required to perform the work.

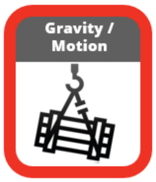
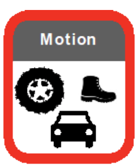
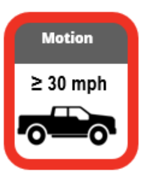
APPENDIX 2 – ENERGY SEVERITY DISTRIBUTION

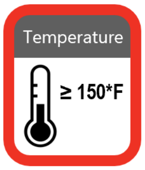
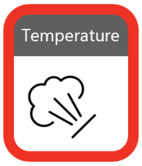
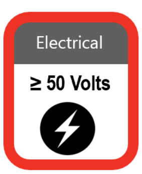


Note: Green corresponds to energy levels less than 500 Joules, where the most likely injury severity is first-aid; yellow corresponds to energy levels between 500 and 1,500 Joules, where the most likely injury severity is medical case or lost work-time; and red corresponds to energy levels above 1,500 Joules, where the most likely severity level is a serious injury or fatality (SIF).

APPENDIX 3 - ICONS FOR ASSESSING SIF POTENTIAL

The following icons represent hazard types that are categorically almost always in excess of 500 ft-lbs of physical energy. If an observer is uncertain if a hazard meets the intent of one of the icons, they should proceed to using the equations provided in Appendix 3 (or the corresponding energy calculator available at powertopreventsif.com).

Icon	Description
 Suspended Load	Most suspended loads require specialty equipment to lift more than 500 lbs of load higher than 1 foot off the ground. In such a case, the suspended load would be more than the high-energy threshold. Suspended loads have both gravity (vertically lifted load) and motion (lateral movement of the load).
 Fall from Elevation	Considering the average weight of a human is over 150 lbs, 4 feet of elevation (measured from the ground surface to the bottom of the feet) exceeds the high-energy threshold.
 Mobile Equipment/Traffic with Workers on Foot	Due to the mass, most mobile equipment, including motor vehicles, exceeds the high-energy threshold when the equipment or vehicle is in motion. The energy exposure is taken from the point of view of the worker on foot and not the equipment operator or vehicle driver. Note: For work zone traffic only, an incident occurs only when a vehicle departs from the intended path of travel and is within 6 ft of an exposed employee or if an employee enters the traffic pattern.
 Motor Vehicle Incident (occupant)	Estimates of the motor vehicle speed typically involved in serious or fatal crashes vary greatly from the National Transportation Safety Board, National Highway Transportation Safety Association, and the U.S. Department of Transportation. The team selected a conservative estimate of 30 miles per hour as the high-energy threshold. This energy exposure is taken from the point of view of the vehicle occupants, including the driver.
 Heavy Rotating Equipment	Computing mechanical energy can be complex, as it requires estimates of the moment of inertia and angular velocity for rotating objects and stiffness and displacement for tension or compression. Thus, all heavy rotating equipment beyond powered hand tools typically exceed the high-energy threshold and should be considered high energy.

 High Temperature	According to the American Burn Association, exposure to any substance greater than or equal to 150 degrees Fahrenheit typically causes third degree burns when contacted for 2 seconds or more.
 Steam	According to the American Burn Association, any circumstance with the release of steam exceeds the high-energy threshold.
 Fire with Sustained Fuel Source	According to the North American Combustion Handbook, a lightly combustible material like paper burns at approximately 700 degrees Fahrenheit, far exceeding the temperature threshold. Fire with a sustained source of fuel exceeds the high-energy threshold.
 Explosion	Most incidents described as an explosion exceed the high-energy threshold.
 Excavation or Trench	An exposure to unsupported soil in a trench or excavation that exceeds 5 feet of height exceeds the high-energy threshold. Typically, for each foot of depth, soil pressure increases by about 40 pounds per square foot (psf). Thus, at 5 feet of depth, the pressure is approximately 200 psf.
 Electrical Contact with Source	Electricity equal to or exceeding 50 volts is sufficient to result in serious injury or death according to the NFPA 70E.
 Arc Flash	Any arc flash exceeds the high-energy threshold because of the voltage exposure, according to the NFPA 70E. Also, permissible distances are covered in OSHA Standard 1910.333 and section 1910.333(c)(3)(ii)(C) in particular.

 High Dose of Toxic Chemical or Radiation	Exposure to toxic chemicals or radiation. An industrial hygienist, chemist, toxicologist, or other competent person should be involved in the assessment of toxicity and acceptable exposure limits. The following reference should be used to judge acceptable exposure limits: ▪ Immediately Dangerous to Life or Health (IDLH) Values from the Center for Disease Control: https://www.cdc.gov/niosh/idlh/intridl4.html ▪ Exposures which reduce oxygen (O_2) levels below 16 percent ▪ Corrosive chemical exposures (pH <2 or >12.5)
 Energy Calculations	Some high-energy hazards do not correspond to one of the preceding 13 high-energy icons. For example, tools and materials at height, hoses under pressure, and powered hand tools may be high energy under some, but not all, circumstances. When unsure, energy magnitude must be estimated using the equations shown in Appendix 5 or the energy calculator available at: http://tinyurl.com/2s37csu3 If the amount of energy is estimated to be more than 500 ft-lbs of physical energy, the hazard should be marked as high energy.

APPENDIX 4 – ENERGY COMPUTATIONS

The approach described in this guide is based upon a recent study of more than 500 injuries that demonstrated that the magnitude of energy (estimated in Joules) is a strong predictor of injury severity. To arrive at this conclusion, the researchers reviewed the circumstances surrounding each injury, estimated the energy severity while blind to the outcome, and determined the distribution of energy magnitude by injury severity level. The salient conclusions were as follows:

- Hazards involving 500 ft-lbs or less energy are most likely to cause a less-than-serious injury (low energy).
- Injuries involving more than 500 ft-lbs of energy are most likely to cause a serious injury or fatality (high energy).

These conclusions serve as the basis for the forthcoming energy assessments and thresholds. It should be noted that the original study did not involve all energy sources. In this guide, it is assumed that the energy thresholds apply to all hazards that are physical in nature.

In the following case examples, imperial units are used, but all computations are made using the metric system. The conclusions are converted back to imperial units for interpretation.

Gravity

Gravitational energy represents the potential energy inherent in an object owing to its elevation relative to a lower reference point. This form of energy is intrinsically linked to the gravitational force and is contingent upon two fundamental factors: the mass of the object or individual and the separation distance between said entity and the chosen reference point. In the context of occupational safety, incidents resulting in injuries stem from the release of gravitational energy, which subsequently undergoes conversion into kinetic energy. Such injuries manifest either when an object in descent imparts its kinetic energy onto a worker or when the worker descends to a lower position, experiencing the consequential effects of gravitational energy.

Gravitational Energy (E) exhibits a direct proportionality to the mass of an object or individual, their height above a reference point, and the gravitational constant denoted as G. In the International System of Units (SI), mass is quantified in kilograms (kg), height in meters (m), and the gravitational constant (G) is standardized at 9.8 m/s^2.

_E_ = mass x height x gravitational constant

Examples:

- 200 lb (90 kg) falls 15 feet (4.6 m)

E = 90 kg x 4.6 m x 9.8 m/s^2 = 4,057 Joules
E = 4,057 Joules x 0.74 ≈ 3,000 foot-pounds
Conclusion: High energy

- 1 lb (0.45 kg) tape measure falls on a worker from 10 ft (3 m)

E = 0.45 kg x 3 m x 9.8 m/s^2 = 15 Joules
E = 15 Joules x 0.74 ≈ 10 foot-pounds
Conclusion: Low energy

Motion

Motion energy, also known as kinetic energy, pertains to the translational movement of an object through space. It encompasses all forms of motion except those induced by gravitational forces, mechanical rotation, tension, or compression. The magnitude of motion energy hinges on the object's mass and exhibits exponential dependence on its velocity.

Motion Energy (E) is contingent upon the mass of the object and experiences exponential growth with respect to the object's velocity. In the International System of Units (SI), mass is quantified in kilograms (kg), and velocity is measured in meters per second (m/s). In imperial units, mass is represented in pounds (lbs), and velocity is expressed in miles per hour (mph). As a point of reference, 1 m/s is equivalent to 3.6 kilometers per hour (kph) or 2.2 miles per hour (mph).

$$\boldsymbol{E = 0.5 \times \text{mass} \times \text{velocity}^2}$$

<u>Examples:</u>

- 2,646 lbs (1,200 kg) vehicle strikes worker at 25 mph (11 meters per second or 40 kph)

E = 0.5 x 1,200 kg x (11 m/s)^2 = 72,600 Joules
E = 72,600 Joules x 0.74 ≈ 53,000 foot-pounds
Conclusion: High energy

- Workers carrying a 220 lb (100 kg) pipe strike the torso of another worker at 3 mph (5 kph or 1.34 m/s)

E = 0.5 x 100 kg x (1.34 m/s)^2 = 90 Joules
E = 90 Joules x 0.74 ≈ 66 foot-pounds
Conclusion: Low energy

Electrical

Electrical energy, also referred to as electrostatic potential energy, poses risks primarily when charged particles are introduced into the body as an electric current. This current undergoes conversion into thermal energy as it traverses through the human body, perturbing its internal equilibrium. To facilitate the utilization of this tool for estimating electrical current, we consider the resistance of the human body as 1,500 ohms and assume that all electrical energy dissipates as heat. The magnitude of injury is directly proportional to the exposure time and exhibits exponential dependence on the voltage. The estimation of electrical energy can be approached in two ways: by considering the current (amperage) or by examining the voltage and contact time.

Electrical energy relies on time measured in seconds (s), voltage (V), amperage (A), the assumed resistance of the human body (1,500 ohms), and the assumption that all electrical energy transforms into heat. These computations remain consistent regardless of whether SI or imperial units are employed.

$$E = \text{time} \times \text{voltage}^2 / \text{resistance} \qquad \text{OR} \qquad E = \text{time} \times \text{current}^2 \times \text{resistance}$$

Examples:

- Worker touches a 220V wire for 2 seconds

$E = 2s \times 220\ V^2 / 1{,}500\ ohm = 64.6$ Joules
$E = 64.6$ Joules $\times\ 0.74 \approx 48$ foot-pounds
Conclusion: Low energy

- Arc flash for 0.05 seconds inside a 10kV circuit breaker

$E = 0.05s * 10{,}000\ V^2 / 1{,}500\ ohm = 3{,}333$ Joules
$E = 3{,}333$ Joules $\times\ 0.74 \approx 2{,}500$ foot-pounds
Conclusion: High energy

Pressure

Pressure energy is typically stored within containers, such as vessels, cylinders, and tanks, in the form of compressed gases or liquids. The accumulation of pressure energy exhibits a linear relationship with both the pressure residing within the container and the volume of said container. It is essential to acknowledge the equal significance of both these variables in the context of pressure energy analysis.

Pressure energy hinges on the pressure contained within the vessel and is typically measured in pounds per square inch (psi), with 1 psi equivalent to 7,000 Pascals (Pa). To estimate the volume of a vessel, we employ the metric system, where 1 liter corresponds to approximately 0.264 gallons. Furthermore, for cylindrical vessels, which are prevalent in such scenarios, the volume can be approximated as 3.14 times the square of half the vessel's diameter multiplied by the vessel's length, all measured in meters. In the case of linear vessels such as pipes, the energy estimation is conducted on a per meter basis by estimating the pressure within the pipeline (psi) and the diameter of the pipe (m). 1 joule equals to 1 Pascal*m^3.

For Vessels: ***E (Pa * m^3) = 7,000 x pressure (in psi) x 0.001 x volume (in L)***

For Pipes: ***E = 7,000 x pressure (in psi) x π (0.5 x diameter (in m))^2***

<u>Examples:</u>

- Welding with a 2.5 gallon (10-liter) acetylene cylinder at 250 psi (1,724 kPa)

E = 7,000 x 250 psi x 0.001 x 10 L = 17,500 Joules[1]
E = 17,500 Joules x 0.74 ≈ 12,950 foot-pounds
Interpretation: High energy

- Working near a 2-inch (5 cm) natural gas line at 40 psi (275 kPa)

E = 7,000 x 40 psi x 3.14 x (0.5 x 0.05)^2 = 550 J
E = 550 Joules x 0.74 ≈ 400 foot-pounds
Interpretation: Low energy

[1]*Note that in these equations and in the associated energy severity assessment tool, pressure is estimated for SI units in pounds per square inch (psi) rather than kilopascals (KPa). This convention has been used because psi is the typical convention used in most industrial applications. Pounds per square inch may be converted to kPa at 1 psi = 6.89 kPa.*

Mechanical

Mechanical energy is typically stored within stationary systems in two primary forms: rotational energy (E_r) and elastic energy (E_e). Rotational energy involves spinning components such as grinders, turbines, gears, or pulleys, while elastic energy resides in objects exhibiting spring-like properties, particularly those experiencing tension or compression such as a cable in tension.

Rotational energy (E_r) hinges on two key parameters: the object's rotational inertia (I), influenced by both its mass and shape, and the angular velocity. Rotational inertia (I) is measured as I = 0.33 x weight x length^2 for a rod or I = 0.5 x weight x radius^2 for a cylinder. For a rod, this assumes rotation about one end. For a cylinder, this assumes rotation along the z axis. Angular velocity is measured in radians per second where 1 rotation per minute (rpm) equates to approximately 0.104 radians per second.

In contrast, elastic energy (E_e) depends on the stiffness of the object (k) measured in Newtons per meter. For example, a spring that extends by 10 cm when supporting 85 kg (830 Newtons) has a stiffness of k = 8,300 N/m. The distance in meters is the difference between the rest length and the current length.

For rotation: ***E_r = 0.5 x I x angular velocity ^{2}***

For tension or compression: ***E_e = 0.5 x k x distance ^{2}***

Examples:

- A grinder wheel with a 4.5-inch (0.114 m) diameter weighing 300 grams is rotating at a speed of 11,000 RPM (1,144 rad/s).

I (kg x m2) = 0.5 x 0.3 kg x (0.114m / 2)^2 = 0.00049 kg x m^2

E_r = 0.5 x (0.00049 kg x m^2) x (0.104 x 11,000 rpm)^2 = 320 J

E_r = 320 * 0.74 ≈ 237 foot-pounds

Conclusion: Low energy

- Cable extends by 10 inches (0.25 m) while supporting 1,000 lbs (453 kg or 453 x 9.8 = 4,448 N).

k = 4,448 N/0.25 m = 17,792 N/m
E_e = 0.5 * 17,792 N/m * (0.25 m)^2 = 556 Joules
E_e = 556 Joules x 0.74 ≈ 411 foot-pounds
Conclusion: Low energy

APPENDIX 5 – HECA SAMPLING TABLE

Sample Size Summary (Monthly)						
		Confidence Interval (Marginal Error = 5%, Population proportion = 50%)				
Worker Hours	Estimated HECA Opportunities	75%	80%	85%	90%	95%
10,000	17	15	15	15	16	16
20,000	33	27	28	29	30	31
30,000	50	36	38	40	42	44
40,000	67	44	47	50	53	57
50,000	83	51	55	59	64	68
60,000	100	57	62	67	73	79
70,000	117	62	68	75	82	89
80,000	133	66	74	81	89	99
90,000	150	70	78	87	96	108
100,000	167	74	83	92	103	116
110,000	183	77	87	97	109	124
120,000	200	80	90	102	115	132
130,000	217	82	93	106	120	139
140,000	233	84	96	110	125	145
150,000	250	87	99	113	130	151
160,000	267	88	102	117	134	157
170,000	283	90	104	120	138	163
180,000	300	92	106	123	142	168
190,000	317	93	108	125	146	174
200,000	333	95	110	128	149	178
210,000	350	96	112	130	153	183
220,000	367	97	113	132	156	188
230,000	383	98	115	135	159	192
240,000	400	99	116	137	161	196
250,000	417	100	118	138	164	200
260,000	433	101	119	140	167	204
270,000	450	102	120	142	169	207
280,000	467	103	121	144	171	211
290,000	483	104	123	145	173	214
300,000	500	105	124	147	176	217
310,000	517	105	125	148	178	220
320,000	533	106	126	149	179	223
330,000	550	107	126	151	181	226
340,000	567	107	127	152	183	229
350,000	583	108	128	153	185	232
360,000	600	108	129	154	186	234

370,000	617	109	130	155	188	237
380,000	633	109	130	156	190	239
390,000	650	110	131	157	191	241
400,000	667	110	132	158	192	244
410,000	683	111	132	159	194	246
420,000	700	111	133	160	195	248
430,000	717	112	134	161	196	250
440,000	733	112	134	162	198	252
450,000	750	112	135	162	199	254
460,000	767	113	135	163	200	256
470,000	783	113	136	164	201	258
480,000	800	114	136	165	202	260
490,000	817	114	137	165	203	261
500,000	833	114	137	166	204	263

APPENDIX 6 – REFERENCES

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Edison Electric Institute
701 Pennsylvania Avenue, NW
Washington, DC 20004-2696
202-508-5000 | www.eei.org