What standard fuel models miss

A framework for utility corridor fire risk

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Executive Summary

Electric utilities in the United States spend $6–8 billion annually on vegetation management, yet cumulative liability from utility-caused fires in the past decade exceeds $50 billion (Verisk, 2025). Utilities have responded with grid hardening, protective technologies that reduce ignition probability at the equipment level, and sophisticated multi-layered risk frameworks. These investments have reduced ignition rates and created a suite of new innovations to curb the extent of damage. However, when ignitions do occur, the outcome depends on the fuel conditions at the point of failure, and the data characterizing those conditions has not kept pace with the rest of the risk framework.

Utility-caused ignitions occur at known infrastructure locations: specific poles, spans, and towers whose positions are mapped to sub-meter accuracy. The fuel layer feeding utility fire spread simulation relies on categorical fuel model classifications at 30-meter resolution, derived from products designed for landscape-scale suppression planning in natural systems. But utility-managed corridors, maintained through planned cyclic disturbance, produce fuel conditions that fall outside the classification framework these landscape-scale products were built on. When the fuel classification at a corridor location does not reflect what is actually present at the conductor, the fire behavior models that consume it have the potential to mischaracterize both ignition receptivity and spread behavior at the locations where utility fires start.

Utility corridors create three specific problems for standard fuel models. First, corridors are narrower than the 30-meter pixel, so a single classification typically straddles both managed interior and adjacent unmanaged vegetation, describing neither accurately. Second, corridors undergo cyclic mechanical disturbance that produces fuel conditions outside the natural fuel complexes the models were parameterized to represent. Third, canopy removal over the managed width eliminates the microclimate buffering that slows fuel drying, causing corridor fuels to follow different moisture trajectories than adjacent forest under the same weather and potentially crossing ignition thresholds that landscape-scale indicators do not detect.

Several developments suggest that corridor-specific fuel assessment at asset-level resolution is feasible. Commercial satellite imagery at 30-centimeter resolution can resolve individual trees, shrub clusters, and fuel gaps that are invisible at 30 meters. Domain-expert labeling of corridor fuel conditions offers a path toward training data drawn from managed environments rather than from the natural systems that calibrated existing products. Hazard computation integrating fuel classification, spatial arrangement, and moisture response at the span level has shown preliminary agreement with independent federal fire modeling outputs. The analytical workflow may also benefit from reorientation: rather than running landscape-scale spread models and overlaying infrastructure, the approach could start from the infrastructure, characterize fuel hazard at each asset, and model spread outward from identified high-risk ignition points.

The sections that follow trace the problem from its origin in standard fuel model design, through the specific ways those models break down in utility corridors, to what a corridor-specific alternative requires and what research priorities remain.

1. Introduction:

The Utility Wildfire Prevention Challenge

Much of the U.S. electrical grid passes through fire-prone landscapes. Across the West, the Great Plains, and parts of the Southeast, utility transmission and distribution lines cross grasslands, chaparral, pine forests, and mixed-conifer systems that evolved with periodic fire as an ecological process. Fire suppression over the past century has altered fuel accumulation in many of these systems (Covington & Moore, 1994; Hessburg et al., 2005), and climate change has extended fire seasons and intensified fire weather (Abatzoglou & Williams, 2016), with drought indices indicating persistent drying trends across forested regions and projections of substantially longer high-fire-potential seasons through the end of the century (Brown et al., 2021). But the underlying reality is that fire is a natural component of these landscapes, not an anomaly. The goal for utilities operating in fire-prone territory is to mitigate risk through every actionable lever, including cross-boundary partnerships with land managers and fire agencies, contributions to climate and resilience investments at the landscape scale, and the operational work of maintaining equipment and managing vegetation in their own corridors. Among these levers, the conditions under which equipment failures translate into ignitions are among the most directly actionable, and the fuel data characterizing those conditions is the focus of this paper.

Recent history illustrates both the scale of the challenge and the consequences when prevention falls short. The 2018 Camp Fire, which originated at PG&E transmission equipment on the Caribou-Palermo line, killed 85 people and destroyed nearly 18,000 structures in what remains California's deadliest and most destructive wildfire; a subsequent global settlement of approximately $13.5 billion resolved claims from the Camp Fire along with several earlier California fires (CAL FIRE, 2019). The 2023 Lahaina fire, linked to downed Hawaiian Electric power lines during a high-wind event, killed 102 people and led to a $4.037 billion global settlement among seven defendants (Hawaii Office of the Governor, 2024). The 2024 Smokehouse Creek Fire, the largest wildfire in Texas history, ignited when a decayed Xcel Energy distribution pole, which was flagged for priority replacement three weeks earlier, broke at ground level, dropping energized lines into dry vegetation and burning over one million acres of Texas Panhandle ranchland, killing three people and an estimated 15,000 head of cattle (Texas A&M Forest Service, 2024). The 2025 Eaton Fire, which investigations have linked to Southern California Edison transmission equipment in Eaton Canyon, killed 19 people and destroyed more than 9,400 structures in Altadena before full containment on January 31, 2025 (U.S. Department of Justice, 2025).

These fires share a pattern that compounds the difficulty of prevention: equipment failures often coincide with extreme weather (high winds, low humidity, dry fuels), meaning ignitions occur exactly during the conditions that make containment hardest (Miller et al., 2017). And because utility infrastructure by its nature connects populated areas to the grid, transmission and distribution lines traverse the wildland-urban interface, placing structures and lives at immediate risk in ways that backcountry lightning ignitions typically do not. Together, these factors make the quality of fuel data feeding utility risk models a first-order concern. If the fuel characterization is wrong at the locations where ignitions actually start, the risk model misrepresents both how readily fire establishes and how it behaves once established.

1.1 Investment and Its Limits

Utilities have responded with sustained, large-scale investment across multiple mitigation strategies. PG&E's 2020–2022 wildfire mitigation plan obligations ultimately exceeded $11.7 billion across infrastructure hardening, vegetation management, and operational changes (CalMatters, 2024). California's three major investor-owned utilities together spend over $1 billion per year on vegetation management alone (CPUC, 2024). Grid hardening efforts include covered conductors that prevent arcing from vegetation contact, undergrounding high-risk lines at costs ranging from approximately $2.7 to $4 million per mile (NARDAC, 2025; CalMatters, 2024), replacing aging equipment, and installing fire-resistant composite poles. Protective technologies have advanced rapidly: fast-trip settings increase the sensitivity of circuit breakers, reclosers, and fuses to de-energize faulted lines within a tenth of a second and disable automatic reclosing that could re-energize into a potential ignition source (CPUC, 2023), and Rapid Earth Fault Current Limiters, deployed at scale across Victoria, Australia following the 2009 Black Saturday bushfires, detect ground faults and reduce fault current to near-zero quickly enough to prevent sustained arcing (Energy Safe Victoria, 2024). Utilities have deployed dense networks of weather stations and high-definition cameras for situational awareness, and Public Safety Power Shutoff (PSPS) programs provide a last-resort option to de-energize circuits during extreme fire weather. These programs, taken together, have meaningfully reduced ignition rates; PG&E has reported a 65–80% reduction in CPUC-reportable ignitions on circuits enabled with Enhanced Powerline Safety Settings since program launch (PG&E, 2024).

The risk frameworks guiding these investments are equally substantial. California's major investor-owned utilities combine LiDAR surveys, commercial satellite imagery, field inspection data, outage and ignition history, weather modeling, and equipment condition assessments into quantitative models that evaluate both the likelihood and consequence of wildfire at the circuit level (Mitchell, 2023). These models inform where hardening dollars go, which circuits receive enhanced vegetation management, and when PSPS de-energization is triggered. The analytical infrastructure behind these decisions represents years of development and hundreds of millions of dollars in investment. Within these frameworks, however, one input has not kept pace with the others. The fuel characterization layer that feeds fire spread simulation still relies on categorical fuel model classifications at 30-meter resolution, derived from national products designed for landscape-scale suppression planning in natural systems. Even where utilities subscribe to custom fuel data products that refine and update the baseline classifications, the underlying structure remains: categorical assignments derived from the same natural-systems orientation, delivered at the same resolution. SCE's 2025 RAMP filing acknowledges this directly, noting that regional wildfire hazard models are optimized for macro-level trends and lack the spatial granularity required for site-specific assessment (SCE, 2025). The result is a framework where the resolution and specificity of most inputs have advanced substantially, while the fuel characterization layer remains anchored to products and classification structures that predate the current generation of utility risk modeling.

1.2 The Deterministic Location Problem

Utility-caused wildfires differ from other ignition sources in a critical way: the ignition location is deterministic and can be linked to specific pieces of equipment. Lightning strikes are distributed by topography and storm patterns. Other human-caused ignitions (campfires, cigarettes, agricultural burning, arson) cluster near roads, settlements, and the wildland-urban interface, as decades of research have shown (Syphard et al., 2007; Narayanaraj & Wimberly, 2012; Keeley & Syphard, 2025), but their specific locations are not known in advance. Utility ignitions occur at known infrastructure locations, such as at a particular transmission tower, along a specific span of distribution line, where a conductor might contact vegetation or an arc might reach the ground. Infrastructure inventories locate every pole, span, and tower to sub-meter accuracy, which shifts the analytical problem from predicting where ignitions might occur to characterizing the fuel conditions at each of the locations where ignitions could be initiated.

This changes the assessment problem. For lightning risk, we ask "what is the fuel hazard across this 10,000-acre landscape?" because we do not know where strikes will occur. For utility risk, we ask "what fuel exists at Pole 4457 on Circuit 8, where our conductor could arc?" We need point-specific information at known locations. Every major utility-caused fire reinforces this point. The Camp Fire ignition was precisely identified at Caribou-Palermo Tower 27/222. The Smokehouse Creek Fire started at a specific distribution pole that had been inspected, flagged as decayed, and given a priority-one replacement designation three weeks before it snapped. The Eaton Fire traces to specific transmission infrastructure in Eaton Canyon. The Lahaina fire ignited where a downed line contacted vegetation at a known location. In each case, the fuel conditions within meters of where the equipment failed determined whether ignition established and how the fire initially behaved. This points to a real limitation when applying standard fuel mapping products to utility corridors. Fuel models, which are intended to characterize fuel across vast landscapes, cannot resolve conditions at individual infrastructure assets.

1.3 Purpose and Scope

The following sections trace the mismatch from its origin in the design assumptions of standard fuel models, through the specific failure modes those assumptions produce in utility corridors, to the requirements and early results of corridor-specific alternatives. Sections 2 and 3 review how standard fuel models were designed, what assumptions they carry, and where those assumptions break down in utility corridors. Section 4 describes what corridor-specific approaches require in practice, drawing on results from working hazard and risk assessment systems, and we close by identifying the research priorities and regulatory context that shape adoption.

2. Background: Standard Fuel Models and Their Design Context

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2.1 The Development of Fire Behavior Fuel Models

Modern fire behavior prediction traces to Rothermel's 1972 mathematical model for fire spread in wildland fuels, which computes spread rate and intensity from continuous physical inputs: fuel loading by size class, surface-area-to-volume ratio for each particle class, fuel bed depth, packing ratio, moisture of extinction, fuel moisture content, wind speed, and slope. The physics is general, but the inputs are numerous and impractical to measure at every location on a landscape, requiring either destructive sampling of the fuel bed or expert estimation of parameters that are not directly observable from imagery or casual field inspection.

Anderson's 1982 contribution recognized that these physical inputs co-occur in characteristic patterns across recognizable wildland fuel types: a short grass prairie has a predictable range of loading, bed depth, surface-area-to-volume ratio, and moisture of extinction, just as a closed-canopy timber litter bed has a different but equally predictable set. By measuring these parameters in representative examples of 13 wildland fuel types and packaging the full set of Rothermel inputs for each as a standard fuel model, Anderson reduced the problem from specifying a dozen continuous variables at every point to selecting the correct category from a manageable set, which is what made Rothermel's equations usable across large landscapes. A field crew or aerial photo interpreter identifies the vegetation type present, and the model supplies the physical parameters needed to compute fire behavior. The 13 models were grouped by the dominant fuel stratum carrying fire: grass (Models 1–3), shrub (Models 4–7), timber litter (Models 8–10), and slash (Models 11–13), each defined primarily by how the fuel burns rather than by the species composition of the vegetation.

These 13 models served fire managers for two decades, but natural fuel complexes are more diverse than 13 categories can capture. Scott and Burgan's 2005 expansion to 40 models addressed this by subdividing each group into finer gradations: nine levels of grass loading and height, nine shrub types and densities, nine timber litter conditions, and four slash-blowdown configurations. The expanded set also introduced dynamic fuel models that allow live herbaceous fuel to transfer between the live and dead categories based on moisture content, partially addressing seasonal transitions that the original 13 treated as static. The fundamental architecture, however, remained unchanged: discrete categories, each specifying a fixed set of Rothermel inputs, derived from and validated against field observations in natural wildland systems.

2.2 LANDFIRE: Mapping Fuel Models Across Landscapes

Translating these fuel model definitions into spatially continuous maps covering the entire United States required a national-scale program that could assign the appropriate category to every location on the landscape. The LANDFIRE program, initiated in the early 2000s with mapping beginning around 2004, provides consistent nationwide coverage of vegetation, fire, and fuel data at 30-meter resolution derived primarily from Landsat satellite imagery and field plot data. LANDFIRE maps existing vegetation type, cover, and height, then assigns fuel classifications through rule-based crosswalks refined by regional calibration workshops where fire managers and subject matter experts adjust assignments based on local knowledge. The program produces multiple fuel products, including both the Anderson 13 and Scott & Burgan 40 fire behavior fuel models, the Fuel Characteristic Classification System (FCCS), and canopy fuel layers (bulk density, base height, cover, height). It is the definitive fuel dataset used by the federal interagency fire community: FSim and FlamMap require LANDFIRE inputs for landscape-scale fire behavior simulation, and the Wildland Fire Decision Support System (WFDSS), the operational system used by interagency incident command teams coordinated through the National Interagency Fire Center (NIFC) to model fire behavior during active wildfires, runs entirely on LANDFIRE fuel and topography layers.

LANDFIRE provides consistent fuel data where previously only scattered local maps existed, and it remains under active development with periodic updates incorporating detected disturbances. For landscape-scale fire behavior modeling, 30-meter resolution provides a reasonable balance between spatial detail and computational tractability. Fire spreading across thousands of acres integrates fuel characteristics over large areas; local heterogeneity within individual pixels matters less than capturing the broad spatial pattern of fuel types.

2.3 Intended Scale, Scope, and Assumptions

LANDFIRE's own documentation is clear about where the products are meant to be applied (LANDFIRE, 2023, 2024). Although the data are delivered at 30-meter pixel resolution, LANDFIRE states that the appropriate application scale is much larger than 30 meters and that using individual or small groups of pixels is not recommended. The products are designed to support national and regional strategic planning for large sub-regional landscapes and Fire Management Units covering significant portions of states or multiple administrative entities. LANDFIRE explicitly notes that its products are not intended to replace local-scale data products, and that it is the responsibility of local users, applying LANDFIRE metadata and local knowledge, to determine whether and how the products can be used for particular areas of interest.

The LANDFIRE team recommends a minimum analysis area of at least 5 acres (roughly 22 pixels), reflecting the program's landscape-scale orientation. Every component of the classification system was built from natural wildland inputs. The Anderson (1982) and Scott & Burgan (2005) fuel models describe natural fuel complexes drawn from wildland contexts: grasslands, shrublands, timber types, and post-harvest slash. Field measurements collected in wildland settings parameterized these models, and regional calibration workshops staffed by fire managers with wildland expertise refined the classification rules. The vegetation dynamics models that inform disturbance and succession updates are calibrated to natural disturbance processes (wildfire, insect outbreaks, wind events) and natural succession patterns. The products do what they were designed to do, and they do it across the entire United States, which is a remarkable achievement. Whether applying them to managed anthropogenic environments like utility corridors introduces meaningful errors depends on how closely those corridors resemble the natural systems the models were designed for.

2.4 The Operational Toolchain

LANDFIRE's fuel products feed a chain of fire behavior simulation and decision-support tools that were developed within the same operational context. The National Fire Danger Rating System (NFDRS) combines fuel and weather inputs to generate indices for pre-positioning suppression resources based on regional fire potential (Bradshaw et al., 1983). FSim performs probabilistic fire growth simulation at national scale to support strategic suppression budget allocation and risk assessment (Finney et al., 2011). FlamMap and FARSITE are operational tools used by incident management teams to project fire perimeters and plan containment during active incidents (Finney, 2004). Each tool in this chain was designed around a shared operational assumption: a fire has started or may start somewhere in a landscape, and the problem is assessing its growth potential and allocating management resources accordingly.

Consequence modeling tools used by utilities sit at the downstream end of this chain. These platforms simulate fire growth from specified ignition points to estimate structure exposure and potential losses, and their outputs are by design conditional on the occurrence of an ignition rather than assessments of whether ignition would occur at a given location under current fuel and weather conditions. Utilities consume these outputs within risk frameworks that must assess both the likelihood and consequence of wildfire, and the fuel layer feeding the consequence side of that equation inherits the resolution, classification structure, and design assumptions of the upstream products described in Sections 2.1 through 2.3

3. What Standard Fuel Models Miss in Utility Corridors

Utility corridors are anthropogenic systems maintained through active management. The differences between corridors and the natural landscapes standard fuel models were designed for are structural, not incidental, and they produce predictable failure modes across three dimensions: spatial and temporal resolution, disturbance regime, and fuel classification.

3.1 Spatial and Temporal Resolution

LANDFIRE's documentation states that its products are designed for landscape-scale use but utility-caused fires do not start at landscape scale. An arc at a particular pole ignites whatever fuel exists at that precise point. A typical distribution corridor maintains 15 to 30 meters of clearance; a transmission corridor, 30 to 75 meters. A 30-meter LANDFIRE pixel frequently straddles both managed corridor interior and adjacent unmanaged vegetation, so plurality or averaging rules produce a classification describing the pixel as a whole rather than the conditions at the conductor location within it.

The temporal dimension further compounds the problem. LANDFIRE incorporates detected disturbances in its update cycle, but corridor maintenance (selective tree removal, herbicide application, mowing) modifies fuel conditions without creating the spectral signatures or spatial extent that satellite-based disturbance detection algorithms would flag. Phan et al. (2025) identify temporal latency as one of four major challenges in wildfire fuel mapping more broadly, and the problem is acute in corridors where fuel state can change within a single season. Herbaceous vegetation undergoes seasonal transitions from green to cured within weeks. A corridor that was low-risk in spring following treatment may accumulate significant regrowth within a single growing season, and cured grass under a conductor can become critically dry within days of a heat event.

Scott and Burgan's 40 fuel models accommodate fuel state to a degree, with the slash-blowdown series addressing post-harvest conditions and separate live and dead fuel load inputs allowing some dynamic adjustment, but in all cases the current state of the vegetation enters the model categorically. Once a model is selected to represent current conditions, its structural parameters are fixed: moisture content varies dynamically with weather, while fuel bed arrangement, live-to-dead ratio, and loading remain frozen at the values specified by the category. For natural landscapes on multi-year succession trajectories, where fuel structure changes slowly relative to the update cycle, that approximation is defensible. For corridors where mechanical treatment, regrowth, and curing can shift fuel state within a single season, the gap between categorical assignment and actual conditions may be substantially wider.

A limited body of field validation work suggests an accuracy penalty when applying landscape-scale products at fine spatial scales, even in natural systems. Locally calibrated fuel maps in Boulder County, Colorado predicted 88–91% of burned area in FARSITE simulations, compared with 40–78% when using LANDFIRE data for the same fires (Krasnow et al., 2009). In sagebrush steppe, locally derived fuel models yielded a Sørensen similarity coefficient of 0.70 versus 0.38 for LANDFIRE inputs against observed burn perimeters (Price & Germino, 2022). Keane et al. (2010) reported that LANDFIRE-linked fire hazard predictions matched observed flame lengths only about 44% of the time, with agreement improving when tolerances were widened, a pattern consistent with landscape-scale products that average out local error but do not resolve site-specific conditions. None of these studies examined utility corridors, but all three indicate that accuracy degrades at finer spatial scales in natural systems. Where managed corridors create sharper spatial discontinuities and faster temporal dynamics than forest or rangeland, the penalty may be larger still, though direct evidence is lacking.

These limitations arise from the design intent of the products rather than from calibration shortcomings that better algorithms or faster update cycles could address. The data were built to support area-based questions at landscape scale on annual planning cadences, and adapting them to point-based assessment at individual assets on operational time horizons would require changes to the underlying framework, not refinements within it.

3.2 The Managed Disturbance Regime

The resolution and temporal limitations described above would matter less if the fuel classifications themselves accurately represented corridor conditions at whatever scale they were applied. But the fuel models were parameterized from natural fuel complexes shaped by episodic, spatially patchy, ecological disturbance processes (fires, windstorms, insect outbreaks) that reset succession and create heterogeneous age structures. Utility corridors undergo a fundamentally different disturbance regime, where management occurs on fixed cycles driven by regulatory requirements and operational needs: distribution corridors typically receive treatment every 4 to 8 years, transmission corridors on 8 to 12 year cycles (FERC, 2004). Corridor disturbance is synchronized and spatially uniform, aimed at resetting the entire corridor width to a consistent cleared state, which changes fuel conditions in three ways: it produces fuel beds outside the standard classification framework, it alters the microclimate that governs fuel moisture, and it creates sharp ecological boundaries at corridor margins.

Mechanical clearing cuts stems while leaving root systems intact, triggering vigorous resprouting and favoring disturbance-adapted generalists and invasive species over pre-treatment community composition (Clarke & White, 2008; Lampinen et al., 2015; Eldegard et al., 2015). The resulting fuel bed configurations have no obvious analog in the standard classification set: fresh cut slash in loose piles differs in arrangement and particle size distribution from naturally accumulated litter; herbicide-killed standing woody vegetation differs from both naturally dead-and-down material and the live canopy fuels the classification system expects at those heights; and unburned slash piles left through a fire season create localized zones of extreme loading. Fire science research has paid little attention to direct field characterization of corridor fuels against standard fuel model parameters, though Lopes & Fernandes (2025) documented fine fuel loads ranging from less than 1 to over 10 tons per hectare across mechanically treated Portuguese transmission corridor sites, with slash accumulations that differed in arrangement from natural fuel beds.

Canopy removal during corridor clearing also changes the physical environment in ways that affect how quickly fuels dry. Forest canopies buffer understory microclimate by intercepting solar radiation, reducing wind speed, and maintaining higher humidity through transpiration, all of which slow fuel drying and raise equilibrium moisture content (Rothermel et al., 1986; Whitehead et al., 2006). Cawson et al. (2018) demonstrated that forest understories harbor dead fuels with higher moisture content than open shrublands irrespective of species composition, indicating that canopy cover governs fuel moisture independent of the vegetation type beneath it, and Whitehead et al.

(2006, 2008) documented increased fuel drying rates following commercial thinning in lodgepole pine, directly linking partial canopy removal to fine fuel moisture reduction. In cleared utility corridors, where canopy removal is complete over the managed width, the effect would be more pronounced than in either of those study contexts. Applying canopy-adjusted moisture models or regional fire weather indices to corridor fuels may therefore systematically overestimate moisture content and underestimate ignition receptivity, particularly during moderate drying events where corridor fuels cross ignition thresholds that adjacent forested fuels do not. No paired fuel moisture sensor studies compare utility corridors to adjacent forest in the published literature, and quantifying this divergence under fire weather conditions is a priority research gap.

Finally, utility right-of-way clearing creates sharp ecological boundaries between managed and unmanaged vegetation. Eldegard et al. (2015) studied edge effects along power line clearings specifically and found altered species composition extending into the adjacent forest, with increased abundance of shade-intolerant species and reduced abundance of forest-interior species. Reviews of edge effects at anthropogenic forest boundaries more broadly report elevated tree mortality and windthrow rates at edges compared to forest interiors (Harper et al., 2005; Laurance et al., 2007), increased desiccation stress from altered light and wind regimes, and colonization by disturbance-adapted species. Slash from clearing operations accumulates preferentially along corridor margins where equipment turns and debris is pushed to the edges, creating fuel loading gradients that are spatially abrupt rather than the diffuse transitions between fuel types that standard classifications assume.

None of the studies cited above was designed to test standard fuel model accuracy against corridor ground-truth directly, and direct comparisons of LANDFIRE fuel model assignments to measured fuel characteristics at utility corridor locations using standard fuel inventory protocols, such as those described by Brown (1974), remain sparse in the published literature. Such a study, requiring stratified sampling across corridor age classes and adjacent non-corridor reference sites with paired measurements of fuel loading, fuel bed depth, and particle size distribution, is methodologically tractable with existing protocols and instrumentation, and would provide the direct evidence that current arguments must construct indirectly from adjacent literatures in fire science, forest ecology, and microclimate research. This gap also has a validation consequence: if standard fuel products are mismatched to corridor conditions, comparison against them cannot serve as validation for corridor-specific alternatives, which is a point returned to in Section 4.2.

4. Toward Corridor-Specific Fire Science

The preceding sections identified three requirements that landscape-scale products cannot satisfy at the resolution utility wildfire prevention demands: spatial resolution at individual infrastructure assets, fuel characterization that reflects managed corridor conditions rather than natural fuel complexes, and temporal responsiveness to seasonal and weather-driven changes in fuel state. Any corridor-specific approach that addresses these requirements substitutes the fuel characterization layer that feeds fire behavior modeling, not the fire behavior modeling itself. While the observation and analysis methods change, the underlying physics, including Rothermel's spread equations, moisture damping coefficients, and fire intensity relationships, remain relevant.

4. Toward Corridor-Specific Fire Science

The operational stakes of closing this gap are visible in how utilities make their most consequential decision: when to de-energize. Public Safety Power Shutoffs (PSPS) are the proactive de-energization of power lines forecasted to be in the path of critical fire weather, a last-resort action taken only when other mitigation options are insufficient (PNNL, 2023). The CPUC requires utilities to evaluate risk using a Multi-Attribute Value Function framework in which risk is the product of likelihood and consequence (CPUC, 2018; Mitchell, 2023), with consequence determined through match-drop wildfire spread modeling that assumes an ignition has occurred and projects how the resulting fire grows. De-energization is triggered when both equipment failure likelihood and modeled consequence exceed circuit-specific thresholds. Utilities have made substantial progress in refining both the granularity and the alternatives to PSPS: de-energization decisions are now scoped to circuit segments rather than entire circuits (PG&E, 2025), with thresholds set for each circuit based on event-specific risk (SCE, 2024), and protective technologies including covered conductor, fast-trip relay settings, and Rapid Earth Fault Current Limiters have reduced the circumstances under which PSPS is the only available option.

A circuit segment may nonetheless span miles and encompass hundreds of individual assets whose fuel conditions vary substantially, with some spans sitting in recently treated ground with fragmented fuel and others passing through cured grass over continuous slash accumulations. Mitchell (2023) analyzed the wildfire risk models underlying the three major California IOUs' Wildfire Mitigation Plans and found that the models lack mechanisms to incorporate causal linkage between likelihood and consequence, with missing covariates for extreme weather effects. The bluntness of PSPS can be understood as a rational response to this information gap: the fuel data does not resolve where, within a circuit, ignition hazard concentrates under a given set of weather conditions. Span-level fuel characterization would not eliminate the need for PSPS under extreme conditions, but it could change the decision from a circuit-level binary to a spatially differentiated assessment. As grid sectionalization technology matures, that spatial resolution in fuel hazard becomes increasingly actionable. The following subsections describe what a corridor-specific framework requires across four dimensions: observation scale, hazard computation, moisture response, and consequence integration, drawing on results from working hazard and risk analyses applied to utility transmission and distribution systems.

4.1 Observation Scale

Commercial aerial imagery at 10 to 50 centimeter resolution now resolves individual trees, shrub clusters, and fuel gaps that are invisible in 30-meter products, and airborne LiDAR provides three-dimensional fuel structure including canopy height, base height, and bulk density measurements that serve as direct inputs to crown fire models (Scott & Reinhardt, 2001). The observation technology for asset-scale fuel characterization exists and is available alongside increasingly cost-competitive aerial imagery. Resolution alone, however, does not address the classification problems identified in Section 3, because high-resolution imagery processed through landscape-oriented classification algorithms will produce finer-grained versions of the same categorical mismatch. Phan et al. (2025), in a survey of AI-based fuel mapping methods, note that the majority of existing studies concentrate on limited geographic scales spanning a narrow range of fuel types, leaving a significant gap in the application of high-resolution methods to managed or anthropogenic fuel environments. The analytical framework must change alongside the observation technology: rather than assigning each pixel to a fuel type category, the goal is to characterize ignition hazard at each infrastructure asset as a function of the fuel present, its spatial arrangement relative to the conductor, and its moisture-dependent combustibility, though how best to compute that hazard from high-resolution observations remains an open design question with multiple viable approaches.

A classification framework is only as good as the data it learns from. LANDFIRE's fuel assignments were calibrated through field plot networks and regional expert workshops staffed by fire managers whose experience was in wildland systems (Rollins, 2009), and if corridor fuels follow different succession trajectories and produce different fuel bed characteristics than the natural systems those experts were calibrating to (Section 3.2), then the training data itself is mismatched to the corridor application. Building a corridor-specific classification therefore requires new labeled data drawn from corridor environments. Field inventory at corridor sites using standard fuel sampling protocols (Brown, 1974) across a range of treatment ages and vegetation types provides ground-truth for fuel loading, fuel bed depth, and particle size distribution, but field campaigns are slow and expensive relative to the scale of a typical utility service territory, which may contain tens of thousands of spans across diverse ecoregions. Human-in-the-loop interpretation of high-resolution imagery, where analysts with corridor-specific domain knowledge label fuel types, slash accumulations, and vegetation structure visible at 30-centimeter resolution, provides a scalable complement that can extend coverage well beyond what field sampling alone could achieve. Expert image labeling introduces interpreter variability, but that variability can be quantified and managed through redundant labeling protocols and reconciliation against field-validated reference sites. The practical path forward combines field plots to anchor and validate the classification at representative corridor sites with expert imagery labeling to extend coverage across the full asset base, refined iteratively as field data and model performance feedback accumulate.

4.2 Hazard and Moisture Requirements

Any corridor-specific hazard assessment must satisfy three requirements that follow from the failure modes described in Section 3. First, it must accommodate fuel mixtures rather than forcing each location into a single categorical assignment, because corridor locations typically contain combinations of fuel types that do not correspond to any single standard model. Second, it must account for the spatial arrangement of fuel around each asset, because fire behavior at a point depends on the fuel structure surrounding it (Finney, 2004), and corridor edges where managed and unmanaged vegetation abut with minimal transition create spatial configurations that strongly influence whether ignition would produce sustained fire (Scott & Reinhardt, 2001). Third, it must respond to moisture state, because the same fuel bed that presents low hazard at high moisture content may support rapid spread under dry conditions (Rothermel, 1972; Anderson, 1982), and the canopy-removal effect documented in Section 3.2 means that corridor fuels may cross ignition thresholds that regional fire weather indices do not detect. Linking hazard assessment to corridor-specific moisture estimates rather than regional averages is essential for connecting asset-level risk to actual conditions, though quantifying the magnitude of the canopy-removal drying effect through paired monitoring studies (Section 4.4) is a prerequisite for making this viable in practice.

Early implementations of corridor-specific approaches satisfying these requirements have been deployed across thousands of miles of transmission and distribution corridor spanning multiple utility service territories. The validation problem these deployments face is structural: the landscape-scale products that would serve as natural references (LANDFIRE fuel classifications and FSim burn probability) are precisely the products Section 3 argues are mismatched to corridor-scale assessment, so agreement with them at span scale would validate nothing and disagreement would be indistinguishable from error. What can be checked is directional consistency at the scale these reference products were designed for. Comparisons against FSim (Finney et al., 2011) at circuit scale show that spans classified as higher-priority by corridor-specific hazard assessment are roughly twice as likely to fall in high burn probability areas than spans classified as lower-priority, a rank-based sanity check that corridor-specific hazard rankings are not arbitrary relative to an independent federal product. Direct validation at span scale requires ground-truth ignition outcomes rather than comparison against landscape-scale model outputs, and that validation has not yet been conducted; historical utility ignition records represent the most direct available test and are discussed as a research priority in Section 4.4. Hazard assessment at the asset level, however, is only part of the risk picture; translating it into consequence requires modeling what happens after ignition, which is the subject of the next section.

4.3 Consequence Integration

Assessing fuel hazard at individual assets addresses whether ignition would establish at a given location, but utilities must also evaluate what happens if it does. Fuel hazard alone does not determine risk, because identical hazard scores at two spans represent very different risk levels if one is in remote terrain and the other passes through a dense residential area with high potential for a catastrophic urban conflagration. Translating hazard into risk requires integrating it with consequence, which depends on where fire goes after ignition and therefore on spread dynamics through the surrounding fuel under specific weather and terrain conditions. Corridor-specific fuel assessment as described in the preceding sections addresses whether ignition would establish at a given asset, but consequence assessment requires modeling what happens next: fire growth from the ignition point outward through the surrounding landscape.

This points to a requirement that neither corridor-specific data nor landscape-scale data can satisfy alone. Corridor-specific classification resolves fuel conditions within the managed right-of-way where ignition occurs, but fire that escapes the corridor spreads through the surrounding landscape where LANDFIRE or equivalent products provide the relevant fuel characterization. Consequence modeling therefore requires a hybrid fuel layer that uses corridor-specific data where it is strongest, within the right-of-way, and landscape-scale data where it is strongest, beyond it. Such a hybrid layer would also enable infrastructure-forward spread simulation, meaning fire growth modeled from specific high-risk ignition points identified through corridor-specific assessment rather than from random landscape locations, grounding consequence estimates in actual conditions at the assets where utility ignitions originate.

4.4 Empirical Gaps and Research Priorities

The corridor-specific framework outlined here draws on established fire behavior science and commercially available observation technology, but its development and validation depend on resolving several empirical gaps that the fire science literature has not yet addressed. Four priorities emerge from the arguments in this paper.

The first is a direct comparison of standard fuel model assignments to measured fuel characteristics at corridor locations, the study described at the end of Section 3.2. Published work in this area is sparse, and without it, the magnitude of the classification mismatch that this paper argues for on mechanistic grounds remains unquantified. This priority also addresses the validation problem raised in Section 4.2: because landscape-scale fuel products and the fire simulation outputs built on them cannot serve as span-scale benchmarks for corridor-specific methods, direct validation requires ground-truth data collected at corridor scale, whether through field fuel inventory or through comparison against historical ignition outcomes at specific infrastructure locations. A complementary validation track would assemble utility ignition records across multiple service territories and assess whether corridor-specific hazard rankings predict where ignitions have historically occurred, which is the most direct test of operational relevance. Second, paired fuel moisture monitoring in corridor interiors and adjacent closed-canopy forest would test the canopy-removal drying hypothesis developed in Sections 3.2 and 4.2, establishing whether the predicted moisture divergence is large enough to cross ignition thresholds under fire weather conditions. Third, monitoring plots tracked through complete treatment-to-regrowth cycles would characterize post-treatment fuel succession trajectories and determine how quickly corridor fuel conditions depart from the classifications assigned at the time of the most recent update. Fourth, ground-truthed validation of high-resolution remote sensing for detecting fuel state transitions such as green-to-cured and slash decomposition would establish whether the observation technology described in Section 4.1 can track the seasonal and post-treatment dynamics that static classification cannot capture.

All four studies are methodologically tractable with existing field protocols and instrumentation. The barrier to their completion is not technical difficulty but rather that corridor fuel characterization has not historically been prioritized as a fire science research question.

5. Conclusion

Standard wildfire fuel models serve their intended purpose well. LANDFIRE and the fire behavior fuel models provide landscape-scale fuel characterization that supports regional fire management planning, suppression strategy, and resource allocation across the United States, and LANDFIRE's own documentation is forthright about the appropriate scale of application, explicitly noting that these products are not intended to replace local data for site-specific assessment.

The fires described in the introduction illustrate what this analytical gap looks like in practice. The Camp Fire, Lahaina, Smokehouse Creek, and Eaton fires each ignited at a known infrastructure location where the fuel conditions within meters of the equipment determined whether ignition was established. The fuel data characterizing those conditions was drawn from products designed for landscape-scale suppression planning in natural systems, and the mismatch between the scale at which those products operate and the scale at which utility ignitions occur is the problem this paper describes.

Utility wildfire prevention operates at a different scale, in a different environment, and confronts a different question. The spatial scale is individual infrastructure assets rather than regional landscapes. The environment is managed corridors maintained through cyclic mechanical disturbance that produces fuel conditions outside the range of the natural complexes the standard models were parameterized to represent. The most urgent question, whether a spark at a given span would produce a sustained fire under current conditions, requires connecting landscape-scale fire weather to span-level fuel conditions in a way that the current analytical toolkit was not designed to support.

Corridor-specific fuel assessment at asset-level resolution is technically feasible with existing imagery, fire behavior science, and infrastructure data. Preliminary results from early implementations show agreement with independent federal fire modeling outputs, suggesting that corridor-specific approaches capture real spatial variation in fire hazard while providing the asset-level resolution and moisture responsiveness that landscape-scale products were not designed to deliver. Substantial research gaps remain, particularly in direct field validation of fuel model accuracy at corridor locations and paired monitoring of corridor versus forest fuel moisture dynamics, but the required studies are methodologically tractable and the research agenda is well defined.

The economic and regulatory environment is increasingly aligned with this direction. Industry-wide vegetation management spending of \$6 to \$8 billion annually and cumulative wildfire liability exceeding \$50 billion in the past decade create strong incentives for improved risk assessment, and even modest improvements in the spatial targeting of vegetation management or the scope of PSPS de-energization would produce measurable returns. Since 2018, wildfire mitigation plan frameworks adopted in California and over a dozen other states have moved toward outcome-based evaluation of utility risk models, with compliance tied to liability protections that create direct financial incentives to demonstrate that risk models reflect the best available science (Macomber et al., 2025).

The utility corridor is neither wildland nor working forest. It is a managed anthropogenic system with its own disturbance regime, its own successional trajectories, and its own fuel bed characteristics, distributed across every ecoregion the grid passes through. Utilities are best positioned to run pilots that test whether corridor-specific approaches outperform existing methods on circuits where the ignition history is already known. Regulators can require transparency about the fuel data underpinning utility risk models, which would make the resolution mismatch between that data and asset-level ignition risk visible without prescribing a specific replacement. Researchers have a well-defined set of field studies in Section 4.4 that would give corridor-specific approaches the empirical foundation they currently lack. The tools, data, and methods required are available; what remains is applying them at scale.

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