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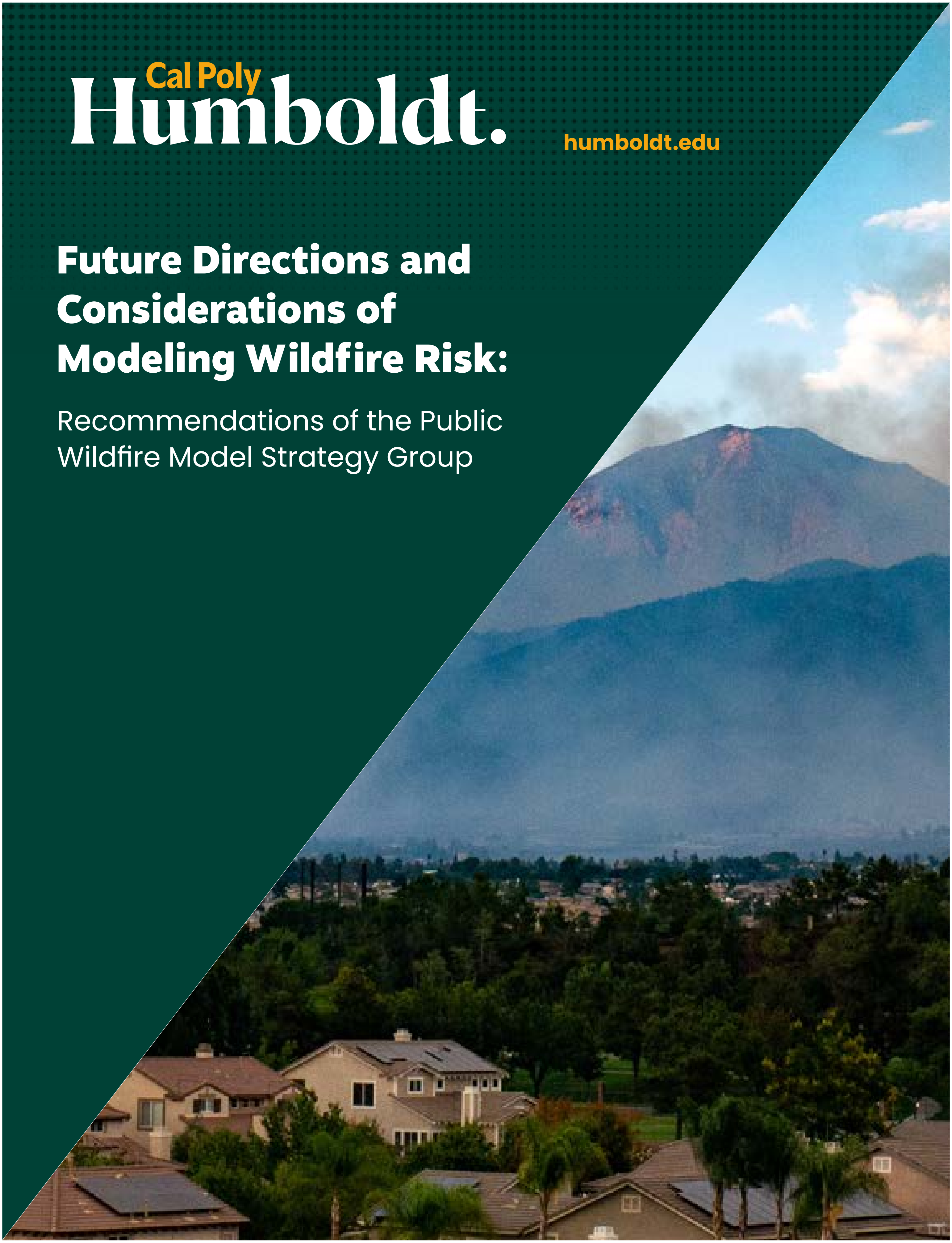

Future Directions and Considerations of Modeling Wildfire Risk:

Recommendations of the Public Wildfire Model Strategy Group

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Executive Summary

The economic vitality of the state of California depends on having a healthy insurance market with affordable and competitive options for homes, businesses, and other assets. State leaders have recognized that insurance availability and affordability has reached crisis proportions and have taken regulatory and legislative action. Insurance market disruption is a direct result of the unprecedented wildfires that have ravaged California over the last decade. The devastating Southern California wildfires of January 2025 are the latest evidence of a trend of growing mega-fires that over the last ten years have produced 15 of the 20 most destructive in terms of property loss in state history.

The insurance market is only one of the economic issues affected by wildfire. Wildfires have major direct and indirect economic impacts, with smoke moving long distances and impacting near- and long- term public health and well-being across California. Wildfires are also fundamentally altering the condition of the state's forested resources and the forest industry, and impacting other businesses such as wine grape growing which is vulnerable to smoke.

While wildfire has been thought to present the most significant risk to communities and towns built at the edge of the forest or shrublands often referred to as the wildland-urban interface (WUI), wildfires have easily approached and crossed these boundaries and moved deep into cities such as Redding, Santa Rosa, Los Angeles, and others, redefining geographic vulnerability. This trend has led to a steady increase in total insured losses to communities in the path of wildfires, which has led to the insurance industry reacting by adjusting their exposure and contracting, and/or increasing premiums. As a result, the FAIR plan, or California's insurance plan of last resort, has become more and more essential.

Understanding when and where communities are most vulnerable is essential to any policy changes that will work at the scale needed to solve the insurance and wildfire problems. California has experienced decades of development and population growth in areas prone to wildfire. Further complicating the situation is that wildfires have impacted communities across the state and have demonstrated that grasslands, shrublands, woodlands, and forests all have the potential of transmitting fire to communities. This means that risk is distributed across the state and is complex in the details.

For decades, the primary focus on fire mitigation has been to establish fuel breaks where fire personnel can work from to attack an oncoming wildfire directly. Most of California's structures have been built without the recognition of the risk and role that embers or radiant heat can play. As a result, most of California's buildings are not properly mitigated against wildfires. Extreme weather-fueled wildfires are also expanding or intensifying the wildfire risk map. This is a problem at the intersection of fire science, climate science, wildland firefighting, home hardening, fire risk mitigation efforts, and the economics of risk, loss, and the cost of recovery. As a multifaceted problem, this crisis demands a collaborative, multisector solution.

- In the summer of 2024 Insurance Commissioner Ricardo Lara initiated an effort to undertake an initial examination of the scope, feasibility, and strategy to develop the nation's first public wildfire catastrophe model. The partnership between public and private universities, nonprofits and a state regulator is unique in California government. California State Polytechnic University, Humboldt (or Cal Poly Humboldt) served as the lead campus for the Public Wildfire Catastrophe Model Strategy Group. Chaired by Dr. Eric Riggs, Dean of the College of Natural Resources and Sciences at Cal Poly Humboldt, the strategy group included representatives from the California State University, the University of California, and Stanford University.

- A primary goal of a public model is to support efforts to prevent large-scale community destruction. A public model can improve research into safety and risk mitigation at the community-wide level, and communication of best practices to all parties involved in community safety. In the insurance field, the definition of a "catastrophe" is an event that occurs at a large scale across multiple homes – i.e., a conflagration compared to a single house fire. We already have best practices based in fire science to prevent the destruction of a single structure. Conflagrations do not happen at the scale of a house, or even a block. They happen at the scale of a neighborhood, a community, or even a city.

- A public model evaluates risks at a broader level that include multiple properties and supports the communication and education to reduce these risks at a larger scale. A public catastrophe model will serve as a benchmark against which privately-created models can be compared. A public catastrophe model provides a means of evaluating and understanding the outputs of private catastrophe models, helping ensure overall risk has been appropriately assessed, and has adequately taken into account individual and community-wide mitigation efforts and other localized factors. A public model should add to our understanding of risk, and therefore the pricing of that risk which is reflected in the setting of insurance rates.

- A public wildfire catastrophe model is a multi-year effort that will require ongoing support and funding. Publicly developed and maintained complex catastrophe models do exist to understand and predict the impact of some natural disasters, including windstorms and flooding. But to date, there are no publicly available digital models in use by agencies and community planners, or consumers, to understand and validate the assessment of risk from catastrophic wildfire events.

- A public model would be a powerful tool for promoting public safety and research, but cannot provide a forecast of future events. We know many Californians are afraid and desperate for definitive answers. Models do not let us travel forward in time. No model specifically predicted that Southern California wildfires would cause the deaths of at least 30 people and destroy more than 10,000 homes – just as no model predicted the outbreak of the Camp Fire, Tubbs Fire, Thomas Fire, or Carr Fire, to name just a few of 15 out of 20 most destructive wildfires in state history that have happened since 2015[1]. Yet many models showed that wildfires in these areas were likely, and that once they started extreme weather events could fuel an urban conflagration. During our discussions group members frequently mentioned the famous words of statistician George

1 CAL FIRE, "Top 20 Most Destructive California Wildfires." https://34c031f8-c9fd-4018-8c5a-4159cdff6b0d-cdn-endpoint.azureedge.net/-/media/calfire-website/our-impact/fire-statistics/top20_destruction.pdf?rev=adaea8332a014a7ebf11dc6fdb3f8e98&hash=EA9A8C492BD9FBAA0FB67C2FEA3FF52E

Box that while "all models are wrong, some are useful." In other words, we should not expect that a public model will tell us where the next wildfire will happen. But it will help reduce community-level destruction by giving both decision makers and the public crucial information of where and how to implement mitigation to minimize future destruction.

Initial recommendation: We recommend the creation of a grant program at the Department of Insurance to fund a center harnessing the power of California's higher-education and non-profit expertise on wildfire safety

Policymakers should create a grant program at the Department of Insurance to create a research and educational center housed at one or more California universities. The grant program can include university and non-profit researchers on modeling, wildfire science, and risk communication. The grant program should specify that any public model supports consistent, accurate data collection on risk mitigation programs at all levels, and publicly available outputs usable by local communities in supporting risk reduction efforts and effective wildfire safety education.

In this initial phase, the new research and educational center would identify the core elements of a public wildfire catastrophe model and a multi-year implementation plan. The center would identify a user base and do initial community education and research about the uses of a model.

This first phase would make further recommendations for ongoing funding and support.

1. Model scale, scope, and complexity
    a. Open-source, community data-driven modeling framework
    b. Inform data collection, such as through a data commons
    c. Address WUI and rural fires and the intersections of these fire regimes
    d. Improve current understanding of mitigation effectiveness

1. Build new tools or adapt existing tools?
    a. Understand the benefits and tradeoffs between modifying existing models vs. creating new models or hybrids of both approaches
    b. Fund and create a public model
    c. Adapt existing open-source models
    d. License and adapt existing private catastrophe models

2. Model structure, governance and funding determination
    a. University-based centers and/or non-profit consortia
    b. Data commons construction and maintenance

Seed funding will support all these actions. Sustained funding is needed for future phases of the model construction process in order to test assumptions, gather new information, create a publicly accessible interface, and communicate the outputs of the model to the public.

Successful models in the public sphere: Transparency, trust, improvement, and validation

A public model can have an important role in expanding knowledge and building public trust about the value of wildfire mitigation efforts. To be realistic, models must capture the network of complex dependencies between interdisciplinary systems, including weather dynamics, climate projections, combustion physics, fuel behavior, and socioeconomic factors that are difficult to master by a single entity.

Public access to assumptions, data sources, and algorithmic logic can engage scientific, fire practitioner, insurance and consumer communities in testing, evaluating and refining the model, and give end-users information about critical limitations or biases that may exist. The availability of standardized benchmarks and open test-beds allows for rigorous cross-model comparisons with private-sector models. Transparency helps models continually evolve and overcome stagnation, outdated science, or oversimplified approximations that could otherwise undermine their utility in mitigating escalating threats.

Our recommendations to the Insurance Commissioner:

- The Commissioner should advocate for funding for research and development on key components of wildfire catastrophe models that overlap with public policy priorities, and that enables comparison of models on a variety of features: scope, scale, uncertainty, testing, etc.

- The Commissioner should identify specific projects to promote public data collection, public communication, training, and educational opportunities that expand and strengthen connection between the public and wildfire risk mitigation.

FULL REPORT AND RECOMMENDATIONS

Section 1: Introduction

Background and Rationale, Charge of the Working Group

Over the last decades, California communities have witnessed increasing wildfire risk and increased losses due to damage in catastrophic wildfires. These risks are not only to working lands and forests, but also to those communities at the wildland-urban interface (WUI) as wildland fires approach and enter developed areas. This trend has led to a steady increase in total insured losses to communities in the path of wildfires, which in turn has led to increasing insurance premiums or inability to secure coverage. The economic vitality of the state depends on having available insurance for homes, businesses, and wildland assets, and the declining state of insurance availability and insurability has reached crisis proportions. This is a problem at the intersection of fire science, climate science, wildland firefighting, home hardening and fire risk mitigation efforts, and the economics of risk, loss and the cost of recovery. As a multifaceted problem, this crisis demands a collaborative, multisector solution.

Advances in computing have improved the ability to model wildfire and its impacts to wildlands and communities. Coupled weather, climate and built environment models exist to predict losses due to catastrophic wildfires as they encounter communities, but most catastrophe models to date are developed privately and are available commercially to insurers. Publicly developed and maintained complex catastrophe models do exist to understand and predict the impact of some natural disasters, but to date there are no publicly available digital models in use by agencies or community planners, or consumers, to understand and validate the assessment of risk from catastrophic wildfire events.

This report provides a strategy framework and initial recommendations on the development and use of public wildfire catastrophe modeling. The framework includes the following themes:

1. Scale, scope, and complexity of potential models
2. Whether to build new models or adapt existing models
3. Catastrophe modeling structure, governance, and funding
4. Immediate steps for the Insurance Commissioner to take

Impetus

In the summer of 2024, Insurance Commissioner Ricardo Lara and university leaders representing the California State University, the University of California, and private institutions agreed to undertake an examination of the scope, feasibility and strategy for how to approach public wildfire catastrophe modeling as a resource for the public.

The partnership between public and private entities and a state agency is unique in California government. California State Polytechnic University, Humboldt (or Cal Poly Humboldt) is the lead campus for this strategy group and invited experts in climate science, forestry, and wildfire safety education from across the CSU and UC systems and private university and non-profit organization partners. The goal and charge of this strategy group was to create a multi-year action plan that will keep California in the forefront of climate innovation and consumer protection.

There is a recognition of the need for improvements in wildfire modeling which will ultimately serve the needs of a wide variety of stakeholder communities and increase the understanding of wildfire at different scales and in varying local environments across the state. Having a diversity of catastrophe models in use in the insurance sector is critical to the advancement of wildfire preparedness and public awareness, insurance analysis, and risk assessment.

Therefore, the existence of public wildfire models and tools is not meant to replace existing private models, but be complementary to existing tools and contribute to the development of better public wildfire data collection, data analysis, and public understanding of wildfire risks. For example, a publicly available model that enabled better research into structure-to-structure fire propagation, urban conflagrations, or relationships between structure density and catastrophe losses could help translate that information to local communities, provide a significant asset to public understanding of fire losses and demonstrate ways to mitigate against future losses.

Models are constructed, combined, and compared across science as tools that provide multiple potential benefits, including the capability for better understanding, testing new factors, and improving data collection. Public wildfire modeling information has the potential to improve public education, planning, and preparation for local wildfire risks.

What did the strategy group do?

The strategy group met with various groups, including Department of Insurance experts, modeling experts, fire chiefs and mitigation authorities, the Insurance Institute for Business & Home Safety, and insurance trade associations. In addition, the strategy group considered existing catastrophe models used in the private sector, the public hurricane catastrophe model created and maintained by the state of Florida, and the development of catastrophe modeling strategies by the Canadian government. After meeting with the above stakeholder groups, the strategy group met internally to discuss, generate ideas, and prepare the information and recommendations in this report.

In 13 meetings between October 2024 and April 2025 the group heard from a range of people including:

- Wildland fire professionals
- Modeling experts
- Insurance trade associations
- Department of Insurance regulatory experts
- IBHS researchers

The group received more than 30 comments via email.

Understanding Catastrophe Models in the Public Sphere

A catastrophe model is a computational model of large-scale disasters, in this case risk of community-scale destruction of property due to wildfire. A catastrophe model is a powerful tool, but it is not a forecast of specific future events.

Publicly developed and maintained complex catastrophe models do exist to understand and predict the impact of some natural disasters, including windstorms and flooding. To date there are no publicly available digital models in use by agencies, community planners or consumers, to understand and evaluate the assessment of risk from catastrophic wildfire events.

The opacity of proprietary fire risk and catastrophe models poses significant challenges in leveraging wildfire science for improved fire risk assessment and community resilience. Wildfires present different challenges for different communities. California has growing areas in the wildland-urban interface, as well as high-structure density areas and low- structure- density areas. Fire spread details and mitigations are distinct for each of these settings. To be realistic, models must capture the network of complex dependencies between natural, physical and human systems, capturing the effects of weather dynamics, climate projections, combustion physics, fuel behavior, and socioeconomic factors that are difficult to master by a single entity. Proprietary frameworks are private and competitive with each other, often obscuring assumptions, data sources, and algorithmic logic.

For such an important issue, like wildfire risk, there are significant public benefits to be achieved from models being sources of research and development to align public policy with a better understanding of wildfire risk. Without a common framework, as well as common data sources, scientific communities are likely isolated, limiting the potential for research to test new ideas that might supplement models in the future, while end-users (e.g., insurers, policymakers) may operate without being aware of critical limitations or biases. Additionally, the absence of standardized benchmarks or open test-beds prevents rigorous cross-model comparisons, testing and evaluation. This presents the risk of leaving any errors undiagnosed and also of leaving innovations siloed or not shared as widely as they could be. Without transparency, models risk stagnating or relying on outdated science or oversimplified approximations, which ultimately undermines their utility in mitigating escalating wildfire threats.

Modeling Wildfire Risk

There are models of fire ignition, spread, occurrence, severity, intensity, as well as models of the likelihood of a structure being destroyed - and the economic loss from that destruction. All of these different facets of fire (and fire regimes) are driven by multiple interacting factors and operate at varying temporal and spatial scales. Also, the direction of influence of one variable on ignition likelihood, for example, may be the opposite of its influence on area burned. Thus, it is always important to understand the model objectives for each model component and how those fit together in an overall catastrophe model. Catastrophe models almost invariably require the use of multiple model types that are coupled together.

Data requirements vary depending upon the model type and scale and require not only observations of wildfire but also the various factors that drive wildfire patterns and patterns of loss. Different types of data are needed to assess parcel-level sensitivity versus landscape or neighborhood-scale fire exposure. Data could include information on home construction and condition, vegetation type, distribution and condition, local and regional fire breaks or mitigations, and current real-time data related to weather conditions and firefighting assets. A successful, fully integrated wildfire risk model would also have to be able to manage the differences in fire behavior between urban conflagrations, where fire is spreading through urban fuels, and the wildfires that destroy structures in rural/exurban/suburban settings.

Finally, all of the relationships captured in current or future models are strongly non-stationary, meaning that they are strongly dependent upon geographical regions, ecosystem types and temporal variability of climactic and weather conditions over many time scales.

Section 2: Elements of Strategy

Purpose of a Public Model - Discussion of End Users

There have long been, and always will be, out of necessity for a competitive market, private models; no part of our recommendations support the idea that a public model should in any way replace private models. A component of the charge of this working group is to make data and modeling more understandable, with the goal of informing policies and programs which could make model output usable by the public to promote public policies that improve safety and preparedness, and reduce losses. To that end, it is important to underscore that a diversity of models is beneficial. There is not a single source of accuracy when evaluating the probabilities of the future. Models will have strengths and weaknesses. The work of this strategy group is to recommend ways to supplement what already exists with recommendations to improve public understanding, data collection, and research related to wildfire risk.

The California Department of Insurance (CDI) is in a relatively new boundary space between public and private assessments of risk from wildfire, especially conflagration-level losses in the Wildland-urban interface (WUI). There is presently a perceived, and actual, disconnect between public sector WUI mitigation policy, especially at the local level, and the private sector analysis of pricing WUI risk. Although there are necessary and important distinctions between mitigation against structure ignition and assessing the financial risk to insurers of paying claims for structures lost or damaged following ignition, they are closely related. Indeed, there are mutual public safety and private profitability benefits to making the relationship between ignition mitigation and risk as clear as possible to homeowners.

There are many kinds of models, and while elements of what we are solving for exist in catastrophe models, our deliberations did not conclude that a public catastrophe model would necessarily, or exhaustively, resolve the disconnect previously described. This is especially true in the absence of a long-term resource commitment required for ongoing development and maintenance. Without sufficient support and validation (rigorous testing and evaluation of model outputs), models are something which can easily be done poorly. And lastly, our state insurance system and markets are responding to unsustainable insured property losses through conflagration secondary to wildfires, not directly to wildfire itself.

Background on fire and home loss issues. How did we get here?

In the following section we develop the source of confusion between WUI property mitigation and the pricing of risk. If we have that right, it suggests that the potential users of a model could include both public and private end users, but would likely have the most utility in various public and non-profit sectors given the deep investment of, and market confidence in, existing proprietary models. An improved understanding of wildfire risk, and especially subsequent conflagration risks to local and state government would have multiple benefits including, but not limited to: prioritization of scarce public mitigation resources, projections of loss on property taxes, a deeper understanding of development impacts (both positive and negative - done correctly, new construction can be a mitigation), a new way to engage municipal bond rating agencies (i.e., S&P has already downgraded some Los Angeles area general obligation municipal bonds for wildfire risk and said it believes such downgrades could effect "...all US issuers...), and help inform optimization of public safety and mitigation investments.

Property owners make mitigation decisions at the parcel level, but conflagrations (which require high structure density), and the modeling of conflagration levels of insured losses occur at the community level. A common granularity for private catastrophe models is 90-square meters (roughly 300 x 300 feet), but the insurance companies using those models can make risk portfolio decisions at even less granularity. The result is that a property owner's home can become an uninsurable risk through factors outside of their control, and for the same reason, stay uninsurable even if they implement and maintain parcel-level mitigations required by public safety organizations. This disconnect at the individual homeowners level between ignition risk mitigation and the pricing of risk transfer to the insurance markets is clearly a source of confusion we must resolve to achieve community levels of independent action.

Until roughly 2017, property loss to wildfire exposure, especially in large numbers (i.e., >500) was a secondary peril to property insurers (15 of California's 20 most destructive fires have occurred after 2017). Consequently, prior to 2017, ongoing private sector development and evolution in data, modeling, and actuarial analysis for WUI vulnerability were generally sufficient, within the limits of Proposition 103 (1988) to price risk. This excerpt from the Insurance Journal (R.J. Lehmann, September 23, 2022) succinctly describes why 2017 was a "hinge point" in California property loss history from wildfire; "A look at data from California's insurance market better illustrates why long-run averages can prove wholly inadequate to project future losses. Homeowner insurers doing business in the state posted a combined underwriting loss of $20 billion for the massive wildfire years of 2017 and 2018 alone. To put that in context, those losses were double the total combined underwriting profit of $10 billion that California homeowner insurers had generated from 1991 to 2016." Changes to Proposition 103 (1988) through the Sustainable Insurance Strategy (SIS, 2023) allowed, among other things, the use of forward-looking data in wildfire catastrophe modeling to project risk. "Catastrophe models are useful because they simulate a wide range of potential scenarios and their likelihoods, including those that have never been observed in the history of a given peril. This is important because if a peril is getting more severe over time, then historical data will always be biased toward underestimating the range of possibilities (emphasis added, see - https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box).

Public sector evolution and development of WUI community mitigations against ignition resistance have been underway prior to the 2017 private sector "hinge point" including but not limited to: USFS Jack D. Cohen's Structure Ignition Assessment Model (SIAM -1995), Living With Fire, University of Nevada, Reno (1997), NFPA Firewise (2002), USFS Jack D. Cohen's WUI Fire Disaster Sequence (2008), Fire Adapted Communities (2009), NIST Wildfire Group (2013), Wildfire Partners in Boulder, Colorado (2014).

Following the 2017-2018 losses, contraction/withdrawal from the market increased, resulting in availability and affordability pressures on property insurance in the state. Moratoriums on non-renewals provided localized and temporary relief to some property owners. Also, prior to the SIS, reinsurance costs were not allowed to be included in rate filings for the admitted market, compounding rate inadequacy during a rapid escalation of billion-dollar natural catastrophes in the US, which in turn escalated reinsurance costs. It was initially thought that increasing implementation of WUI mitigations and risk reduction programs like those listed above would induce a return of favorable insurance availability/affordability underwriting. For at least four reasons this has not yet happened: 1) Such mitigations have not been accomplished at sufficient density/scale, 2) The systems needed for data capture and management of retroactive mitigations have not sufficiently matured, 3) The propagation models among structures are few and immature, 4) There is not yet enough post-fire evidence of mitigation efficacy to make a firm actuarial case for the financial risk reduction value of these mitigations, even though testing and research evidence indicate they do (e.g., IBHS, NIST, FSRI). As more structures are destroyed, more empirical studies are also emerging, e.g., Syphard and Keeley (2019), Mockrin, et al.,(2023), Schmidt, et al. (2024).

WUI conflagrations are a unique catastrophe in that the asset being protected is concurrently the primary source of fire propagation to other assets once multiple near-simultaneous ignitions occur from wildfire embers (i.e., Stage 3 of Jack Cohen's WUI Fire Disaster Sequence). In other words, homes become the fuel that feeds the conflagration. This unique characteristic has created a new need for models that deal with disrupting conflagration propagation (i.e., ignition resistance mitigations), which is different from catastrophe models that enable the pricing of risk. The uniqueness of this peril creates confusion between two different but closely related concepts, catastrophe models that enable the pricing of risk and propagation models that study conflagration spread with an emphasis on understanding mitigation efficacy in disrupting propagation. Mitigation actions are typically in the realm of property owners and public governance whereas risk pricing is largely in the purview of the private insurance market. Consequently, public sector efforts in physical parcel/community level mitigation actions are only a subset of catastrophe modeling and risk pricing considerations. This dynamic creates a perceived disconnect between public guidance on WUI mitigations and the private sector pricing of risk in WUI communities. The California Department of Insurance is located at the regulatory boundary between public consumer protection policy and assuring a sustainable, competitive private insurance market.

Section 3. Recommendations

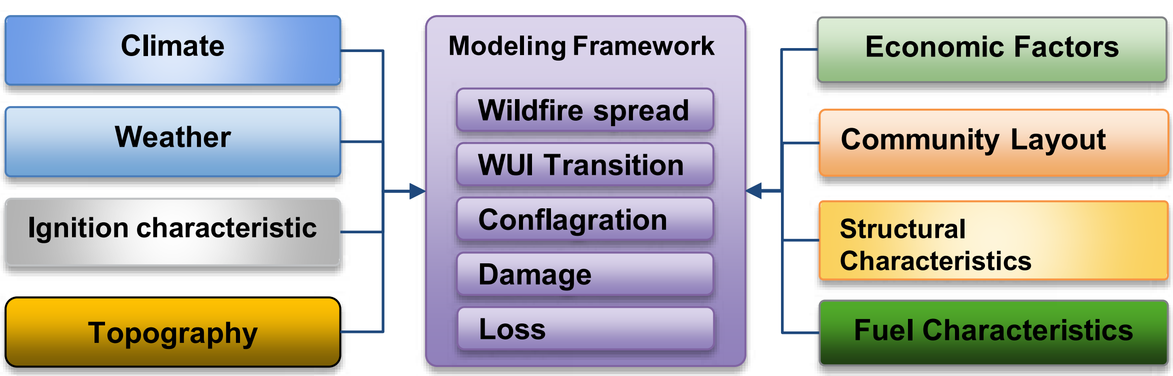
The role of public and private wildfire modeling and the implications for each Private wildfire catastrophe models exist and are used within the insurance sector as part of underwriting strategies and pricing plans by insurance companies. These models have a history, and substantial access to loss data over many years and for many types of events. Because these models are privately constructed, owned, and maintained, it is difficult to know whether there is inconsistency in the determinants of risk or insurability, the degree of adaptability to different use cases.

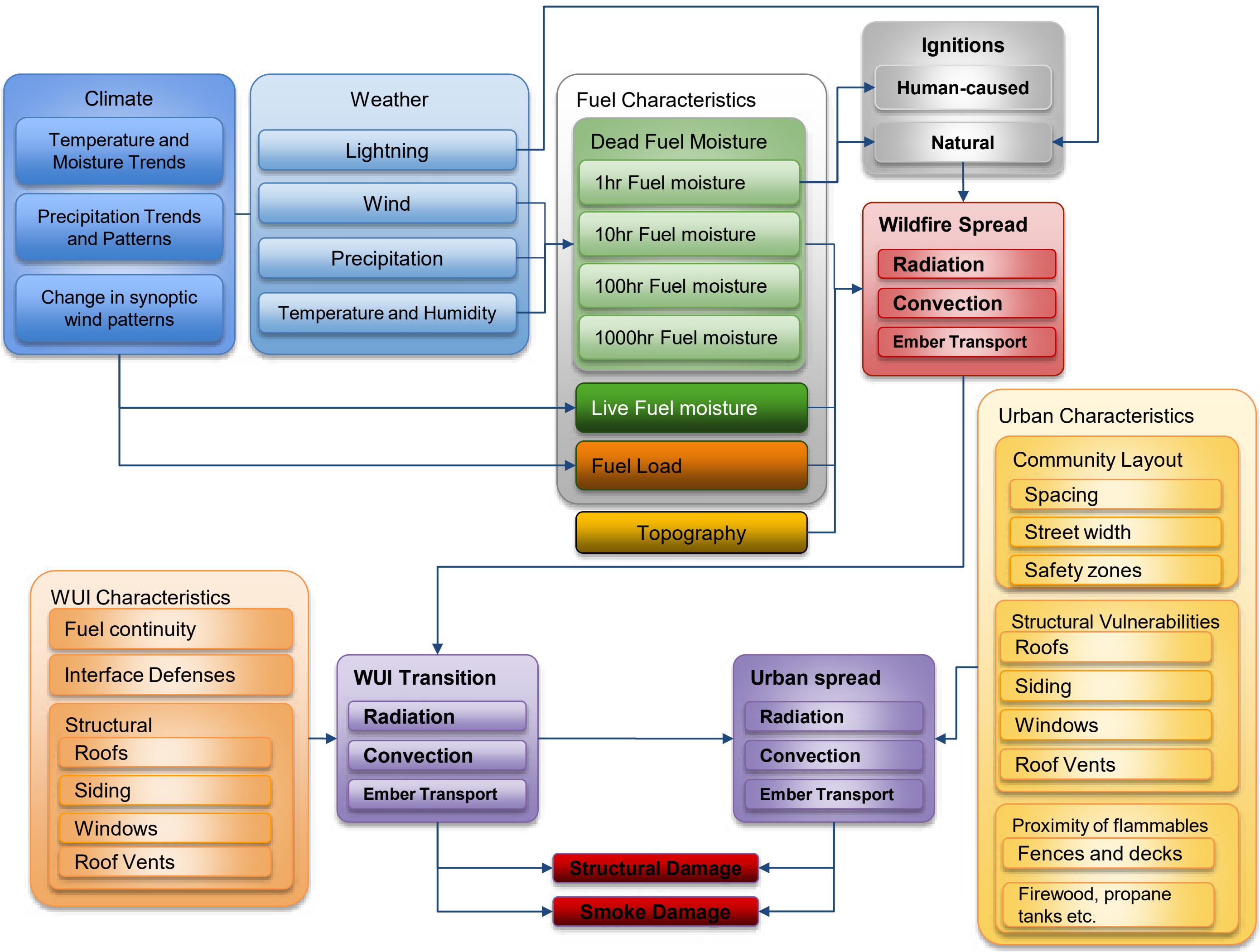
Catastrophe models are commonly used in the insurance industry to predict future losses and assess risk for many natural hazards, however their use for wildfire has been more limited. Some of that comes from the complexity of wildfire modeling. The basis of these models is often an underlying wildfire model which runs ensembles of future scenarios over a range of climate conditions, estimating the likelihood of wildfire and its associated intensity at points across the landscape. Relationships are then used to relate the likelihood and severity of wildfire at any point to potential damage or destruction to assets across the landscape, typically homes or other structures. An economic analysis is then conducted to calculate projected financial losses.

3.1. Scale, Scope and Complexity of a Public Model

Wildfire modeling is typically conducted across a 2-D landscape where fuel (typically vegetation), topography, and weather (wind and moisture) drive the rates of fire spread at any point on the landscape. Because these models are run as ensembles, or groups of many individual simulations, ignition points must be randomly generated across the state and tied to specific weather conditions. There are many ways these can be configured, with ignitions completely randomly spread, tied to past events, biases introduced close to power lines or population, among others. Ultimately fires spread across the landscape for a specified period of time, are combined, and a spatial map of many stacked fire occurrences used to build outputs. Weather is a critical factor in these simulations and there are many ways to incorporate it. Past weather, following atmospheric simulations of multiple past decades can be used to formulate weather, or future projections including the effects of climate change.

Modeling of fire spread through structures and other urban fuels is still in relative infancy. At present only 3 models have been published that model WUI fire spread in the US (Mahmoud and Chulahwat, (2018), Masoudvaziri, et al., (2021), Purnomo et al., (2024), relying on detailed information about structures that do not yet exist in usable form. An early form of post-earthquake fire modeling from the 1950's (Hamada, (1951)) has often been adapted as a means to spread through urban areas. These models all still struggle with missing nuances such as the impact of structure mitigation and fine details beyond the scope of correlations used to build these models. They are still in their infancy, but do provide absolutely necessary fire spread information in these areas. Current catastrophe models, being private, do not generally release the nuances of their urban fire spread modeling approaches.





Fire Model Data Inputs

Fire models rely on diverse data streams, yet critical gaps persist across detection, fuel, and weather domains, hampering accuracy particularly in urban contexts. Satellite-based fire detection (e.g., VIIRS, MODIS, GEOS) offers broad coverage but struggles with urban-scale resolution (≥375 m) and infrequent revisits (twice daily), missing processes critical for urban fire spread. New satellite networks such as FireSat for detection promise improved spatial and temporal resolution, but are not yet available. Higher-resolution fire perimeters (0.5-3 m) from aerial imagery are sparse, often delayed, or unavailable for smaller fires. Fuel mapping via LANDFIRE provides foundational data but lacks standardized urban fuel characterization (e.g., ornamental vegetation, building materials), and updates lag behind landscape changes.

Weather and climate inputs such as reanalysis products (e.g., ERA5), and climate projections (CMIP6), as well as station observations, capture regional patterns but fail to resolve urban microclimates. Fuel moisture data face significant limitations. Dead fuel reanalysis (e.g., Farguell et al. 2024) provides a robust estimate of 10-hour dead fuel moisture however, other classes are not sampled adequately for data assimilation and creating spatial fuel maps. Live fuel moisture estimates rely on the National Fuel Moisture Database's biweekly, labor-intensive samples, with no publicly available reliable spatial product. Urban-specific data are especially scarce; building spacing, material flammability, and fire-resistance ratings are rarely cataloged.

Upcoming initiatives like the WiFire Data Commons (Altintas et al. 2015) are promising but remain incomplete. These gaps propagate uncertainty, particularly in structure-to-structure spread models, where empirical validation is nearly impossible without granular, real-world datasets. Addressing these challenges demands coordinated investment in targeted data collection at all scales, including pre-fire structure, fuel, and topography information, laboratory to full-scale testing of building mitigations, and closer monitoring and data collection during and after destructive events.

Economic Factors

Following simulations of fire spread, catastrophe models must translate fire intensity into structure damage. Damage functions relate flame height to the percentage of the structure that is damaged and depend on factors such as year built, construction type, occupancy type, and number of floors. Also relevant are mitigation measures at the property level including defensible space, vent screens, and building materials. When combined with estimates of rebuilding costs, the structure damage projections can be used to project economic loss due to catastrophic events and the effect of property, neighborhood, and landscape-level mitigation measures on expected annual property loss. The cost of mitigation measures can then be compared to the reduction to the value of expected annual property damage to help prioritize mitigation investments.

Recommendation 3.1

The Commissioner should advocate for funding for research and development on key components of wildfire catastrophe models that overlap with public policy priorities, such as the risk reduction benefits of infrastructure projects, quantifying mitigation effectiveness, the role of structure density in loss estimates, and exploration of data gaps that can be filled by more consistent public data collections.

Continued research and development are critical to effective fuel modeling. A paradigm shift toward open, modular models, built around discrete physical processes, like fuel combustion, wind-driven embers, or structural ignition, would revolutionize the field. By decoupling complex systems into interoperable components, such frameworks allow wildfire scientists, climatologists, and engineers to advance domain-specific modules independently while ensuring seamless integration. For instance, breakthroughs in drought-driven fuel moisture dynamics or urban firebrand transport could be rapidly incorporated without overhauling the entire model. Transparency in design and data flow would enable peer review, reduce hidden biases, and foster trust among policymakers and communities.

Modularity also supports scalable validation: individual processes (e.g., crown fire spread) could be tested against controlled experiments or historic megafires, while the integrated model benchmarks whole-system performance. This approach not only leverages cutting-edge science but also promotes innovation, empowering researchers to refine high-impact areas like climate-vegetation feedbacks or structure-to-structure propagation. Ultimately, open modular models would transform stagnant, opaque tools into adaptive platforms that mirror the interdisciplinary nature of fire itself, advancing both scientific understanding and society’s capacity to mitigate catastrophic risks.

3.2 Build new modeling tools or adapt existing tools?

An open-source, community-driven fire risk modeling framework, created by multi-disciplinary partnerships could unify fragmented research efforts by integrating field observations, laboratory experiments, and computational advancements. Such partnerships could learn from examples like the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), Such a framework would employ a modular architecture, allowing independent development of specialized components (e.g., fuel ignition, urban fire spread, ember transport) while ensuring interoperability through standardized data interfaces.

This approach would enable researchers to refine modules at varying complexities from empirical wildfire spread algorithms to high-resolution computational fluid dynamics for urban wind interactions tailoring tools to diverse needs, from rapid risk assessments to detailed scientific inquiry. Key benefits would include synergy across disciplines, such as validating lab-derived combustion models with field data or incorporating urban flammability metrics from engineering studies, while transparency would foster trust through peer review and reproducible results. Sustaining this vision requires institutional stewardship to coordinate development, maintain core infrastructure, and curate benchmark datasets for validation.

Modern collaboration tools like GitHub would streamline distributed contributions, enabling version control, automated testing, and issue tracking. Challenges like data harmonization and funding gaps could be mitigated through FAIR data principles and climate resilience grants. By mirroring WRF's transformative impact on weather prediction, such a framework could bridge fire science, urban planning, and climate adaptation, democratizing access to cutting-edge tools and accelerating resilience in an era of escalating fire risks.

Recommendation 3.2

We recommend the founding of a grant program to support an open-source, integrative fire risk modeling framework. Such a framework should focus on understanding and communicating the risk of catastrophes and conflagrations to buildings and structures, and establish the foundational information to train and educate the public and future workforces.

3.3 Public modeling structure, governance and funding

To compare existing models or build new models requires coordination among researchers, data tools, and public communications. Ideally this would take place in a consortium setting, potentially a non-profit consortium anchored by a university partner who could provide a stable location to found a center devoted to this purpose.

Such a public modeling center could integrate strategies across field, laboratory, and computational results, identify necessary roles of different organizations and universities, and be the source of validation or verification procedures. Such a center should be located in such a way as to provide the most public benefit, maximize existing expertise and resources, and coordinate among the possible contributors, users, and stakeholders. To build a model requires funding and the organization of a model development team. Research centers have historically been successful ways to organize expertise to inform or create publicly available tools.

This center or group could involve comparisons of models focused the different components of fire that ultimately lead to loss, e.g., ignition location probability; fire size and occurrence, spread and intensity in the wildland; exposure of different types of assets in rural vs. urban settings across different ecosystems; sensitivity at the community/parcel level.

Recommendation 3.3.1
A public model should reside outside of government but not at a private firm. A new center, including one or more universities could provide the independent, expert, publicly accessible structure that would generate trust and broad public benefits from wildfire catastrophe modeling tools and resources.

Recommendation 3.3.2.
A research center established to support the use of publicly available risk modeling should provide mechanisms for broad use of public modeling resources to achieve multiple public benefits, including specifically the training of future workforces, education of undergraduate and graduate students, the use of public modeling information to improve local risk mitigation, and the advancement of modeling research that benefits alignment of public wildfire mitigation policies.

Maintaining a Public Model

If an effort to develop a public model comes into existence inside a center as described above, there will need to be extended discussions at the state and center level about governance of model access, outputs, direction and maintenance.

A public wildfire catastrophe model is a multi-year effort that will require ongoing support and funding. This effort can take place in stages or phases as work progresses. Discussion of mechanisms for funding the continued operation of this center as well as the timing and funding decisions for stages, milestones, and other development activities should be part of the enabling actions that lead to the formation of the center. The scale and length of this effort is substantial, and all partners should understand the level of commitment and availability of support for this continuing, long-term work.

Section 4. Immediate Next Steps
Our Recommendations to the California Insurance Commissioner

Recommendation 4.1
The Commissioner should request funding for a specific research project to create a model inventory that enables comparison on the scope, scale, uncertainty, verification, validation, among other comparisons.

Recommendation 4.2
The Commissioner should use the model comparison study to inform the creation of a consortium of universities and request funding over multiple years.

Recommendation 4.3
The Commissioner should identify specific projects to promote public data collection, public communication, training, and educational opportunities that expand and strengthen connection between the public and wildfire risk mitigation.

Recommendation 4.4
The Commissioner should advocate for seed funding and also identify budget strategies that provide sustained funding for research and development of data and modeling deliverables that will take years to come to full fruition.

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