1 Introduction

During the fall and winter of 2017-18, California residents lived through a devastating series of disasters. After years of drought, devastating wildfires ravaged thousands of homes from Northern to Southern California; deluge rain events after the fires led to catastrophic floods, mudslides and debris flows that washed away bare soil, housesand cars and closed stretches of Highway 101, crippling transportation routes. Over this time, the state received five Major Disaster Declarations, three Emergency Declarations and 23 Fire Management Assistance Declarations – a combination never experienced before.[1] Sixty-five Californians lost their lives and thousands of homes, numerous roads, communication towers, phone and electricity distribution lines, fleet vehicles and parks either were destroyed or sustained damages that are still being tallied and remedied. Against a backdrop of aging infrastructure that some describe as "crumbling" [1,2] these extreme events offer a first-row seat to the fragility of our infrastructure systems and they give us a glimpse of the future in a changing climate. For people to be safe, our communities must be prepared. Our infrastructure must be resilient and sustainable to withstand these growing threats, particularly worsening extreme events.

Our infrastructure must be resilient and sustainable to withstand the growing threats from climate change, particularly worsening extreme events.

Yet, as noted in the 2017 report by the Union of Concerned Scientists – *Built to Last: Challenges and Opportunities for Climate-Smart Infrastructure in California*[3] – California's infrastructure is not. Our infrastructure is aging and deteriorating and, despite recently increasing investment, still requires better upkeep and modernization. Lack of emergency action plans for high-hazard infrastructure, a long backlog of deferred maintenance projects and billion-dollar gaps in spending on infrastructure upkeep plague the state of infrastructure in the fifth largest economy in the world. These truths provide a stark backdrop to the rapidly growing need of investing in new infrastructure and preparing for the accelerating impacts of climate change. Through the Climate-Safe Infrastructure Bill, AB 2800 (Quirk)[2], and with its leadership and foresight in climate change adaptation planning, the State of California is seeking to understand how it can better prepare its existing and new infrastructure for increasingly unpredictable climate conditions that will be significantly different from the current ones. The State is seeking to understand how it can ensure a climate-safe future.

AB 2800 builds on a strong legislative and planning record in California that has sought to lead the nation in global greenhouse gas emission reductions, energy and automotive mileage efficiency and more recently adaptation planning (Box 1.1).

The Climate-Safe Infrastructure bill seeks to build on this impressive legacy and push it forward in critical ways. AB 2800 mandated that a panel of scientists, registered engineers and architects be convened to help the State of California understand how it can best incorporate forward-looking climate information into the state's infrastructure design, planning and implementation. To develop recommendations to the State legislature and the Strategic Growth Council (SGC), and in response to the mandate from AB 2800, the Climate-Safe Infrastructure Working Group (CSIWG) was appointed in July 2017 and convened in January 2018. It is comprised of expert engineers and architect from State agencies and special jurisdictions, bolstered by some of California's leading scientists specializing in climate science, transportation and economics (Box 1.2, Appendix 2).

[1] See: https://www.fema.gov/disasters/state-tribal-government/0/CA.

[2] See: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800, as well as Appendix 1.

Box 1.1: Selective Legislation, Mandates and Adaptation Planning Efforts Influencing AB 2800

- Executive Order S-13-08, 2008
- Safeguarding California, 2009 (and subsequent updates and implementation plans)
- Executive Order B-30-15, 2015
- AB 1482 (Gordon), codifying regular updates to state adaptation plans, 2015
- Annual Five-Year Infrastructure Plans
- State Hazard Mitigation Plan
- California/Regional Transportation Plans, California Water Plan, Central Valley Flood Plan
- Office of Planning and Research's *Planning and Investing for a Resilient California: A Guidebook for State Agencies, 2018*

The Urgency and Opportunity to Invest in a Climate-Safe Future

AB 2800 does not come a moment too soon. From a national perspective, California has an opportunity to take a strong leadership position in the nationwide debate on modernizing and building critical infrastructure. The American Society of Civil Engineers (ASCE) regularly assesses the status of infrastructure across the United States, and has found the nation's infrastructure – on average, across infrastructure types – to deserve no more than a D+ grade[4]. "D" stands for "poor, at risk." AB 2800, building on past infrastructure efforts by State agencies, the Legislature, outside experts and deeply concerned stakeholders, offers an opportunity to show the country how infrastructure can be rebuilt and created with a forward-looking, climate-aware perspective.

In fact, through existing State bonds (e.g., SB 1 for transportation and $5.8 billion in State school bonds for modernization and $39 billion in local school district bonds) as well as recently voter-approved propositions (Prop 1 and Prop 68 for water and natural resources), the State has nearly $62 billion dollars available to invest in built and nature-based infrastructure. In 2018 alone, the Cap and Trade revenues provide another $8.4 billion that are being directed towards climate mitigation and adaptation planning; this is expected to quadruple in 2018. In addition, given the recently elevated national debate on infrastructure, federal infrastructure funds may increase above historical levels.

Box 1.2: Members of the Climate-Safe Infrastructure Working Group (in alphabetical order)

- Dr. Amir AghaKouchak, P.E., University of California, Irvine
- Nancy Ander, P.E., California Department of General Services
- John Andrew, P.E., ENV SP, California Department of Water Resources
- Gurdeep Bhattal, P.E., California Department of Transportation (alt)
- Martha Brook, P.E., California Energy Commission
- Dr. Dan Cayan, University of California, San Diego: Scripps Institution of Oceanography
- James Deane AIA, CDT, LEED AP, PMP, California High Speed Rail Authority/WSP
- Dr. Noah Diffenbaugh, Stanford University
- Dr. David Groves, RAND Water and Climate Resilience Center, Pardee RAND Graduate School
- Dr. Kristin Heinemeier, P.E., University of California, Davis: Energy Efficiency Center
- Dr. Robert Lempert, RAND Corporation, Frederick S. Pardee Center for Longer Range Global Policy and the Future Human Condition (alt)
- Dr. Cris B. Liban, P.E., ENV SP, Los Angeles County Metropolitan Transportation Authority
- Dr. Kyle Meng, University of California, Santa Barbara
- Dr. Deb Niemeier, P.E, NAE, University of California, Davis
- Bruce Swanger, P.E., California Department of Transportation
- Chester Widom, FAIA, California Department of General Services, Division of State Architect

In the meantime, however, 52 of California's 58 counties declared a state of emergency at least once during the floods and fires of 2017/18 and received approximately $3.5 billion in disaster funding[3], a substantial portion of which can be used to rebuild infrastructure, and – where local codes allow – make this infrastructure stronger for a climate-changed future[5]. In addition, California is utilizing disaster funding to create resilience to future disasters exacerbated by climate change by using hazard mitigation post-disaster funds to target drought, wildfire and sea-level rise. To date, $38 million in federal cost share grants for

[3] $1 billion of that was for the debris cleanup after the Northern California fires alone. The final loss total may still change.

managed aquifer recharge projects – some of the first in the nation – have been submitted to FEMA for final review and approval, and additional sea-level rise and wildfire mitigation projects are soon to follow[5]. While these billions of dollars may seem like a windfall, they are only a down-payment on the statewide infrastructure investment needed as we will show in this report. Importantly, these available funds could easily be squandered on maladaptive projects if climate-safe infrastructure policies and guidelines are not put in place today.

Scope and Charge

As mandated in the AB 2800 legislation, the working group has a very specific charge, namely, at a minimum, to consider and investigate:

1. The current informational and institutional barriers to integrating projected climate change impacts into state infrastructure design;
2. The critical information that engineers [and architects] responsible for infrastructure design and construction need to address climate change impacts; and
3. How to select an appropriate engineering design for a range of future climate scenarios as related to infrastructure planning and investment.

It further mandates that, in a report to the State Legislature and the SGC, the working group shall make recommendations to the Legislature that address:

1. Integrating scientific knowledge of projected climate change impacts into state infrastructure design;
2. Addressing critical information gaps identified by the Working Group; and
3. A platform or process to facilitate communication between climate scientists and infrastructure engineers [and architects].

During the first CSIWG meeting, the Working Group developed a process to address the mandated requirements (Figure 1.1). In addition, members identified broader goals that both meet the legislative mandates, but also help further the intended goals of the legislation. As a result, the CSIWG identified a set of outcomes that address these goals. They aimed to identify:

- The **range of infrastructure to be considered** in the work of the WG;
- **Opportunities for State of California to affect how and where infrastructure is built**;
- **Opportunities for integrating forward-looking science** (about a non-static future into infrastructure design);
- **Critical information needs of infrastructure engineers and architects** to address climate change impacts;
- **Critical information gaps**;
- **Informational and institutional barriers** to integrating projected climate change impacts into state infrastructure design; and
- **Ways to select an appropriate engineering design for a range of future climate scenarios** as related to infrastructure planning and investment.

Figure 1.1 At the first meeting, Working Group members co-identify and rank their goals and priorities for how to guide the State in developing climate-safe infrastructure. (Photo: Susanne Moser)

To achieve these outcomes, at the outset, the CSIWG identified what they determined to be an important set of corresponding recommendations that should emerge from the working group deliberations:

- **Policy recommendations** of how to encourage forward-looking infrastructure planning and design;
- **Procedural recommendations** to affect climate-safe infrastructure development process (from planning, design, approval, construction to monitoring);
- **Principles** to guide infrastructure development, maintenance, repair to build equitable and climate-resilient infrastructure;
- **Identification of available tools and information sources** to use;
- **Recommendations on how to lower/overcome barriers** to information use;
- **Research recommendations** to fill information gaps; and
- **Recommendations on capacity building/professional development.**

This report summarizes the CSIWG's deliberations in response to the mandate of AB 2800 and offers recommendations to the California State Legislature and the SGC. Together, these recommendations chart a path toward helping California invest in climate-safe infrastructure. It addresses both the infrastructure that was built decades, even more than a century ago – from

historical bridges, to major dams, highways and buildings – and the infrastructure that will be built in coming years and is meant to last and be used for many decades to come. While this effort initially sought to solve the challenge of incorporating climate information into infrastructure design (something engineers and architects have struggled with for years), the Working Group discovered that the science challenge in moving toward climate-safe infrastructure is significant, but not intractable. Equally difficult, if not more, are those additional challenges that require profound shifts in values, thinking, priority setting and policy commitments.

This report launches from the legislative intent for AB 2800, namely to make California communities safer, to save lives. While saving lives is more likely if decisions are informed by the best available knowledge, science alone will not guarantee our safety. Saving lives is a matter of what and who we as a society value, what we believe deserves our dedicated investment, and thus what decisions we make and actions we take. Investing in a climate-safe future for all is a way of creating a positive legacy for the future. It is *paying it forward*.

Thus, the recommendations in this report have the lofty, yet achievable goal, of incentivizing and inspiring legislators, agency leads, engineers, architects, scientists, consultants and contractors, planners and residents to commit to joining hands in creating a climate-safe future for California.

Key Concepts and Definitions

To ensure that the CSIWG would be able to efficiently address the legislative mandate, it was critical to identify, from the outset, the scope of the infrastructure for the deliberations and discussions, as well as agree upon definitions of the key terminology that would be used throughout the Working Group meetings.

In defining the scope of the infrastructure to be discussed and deliberated on during this process, the CSIWG also thought it important to not only consider individual infrastructure assets but to consider these individual assets as part of a broader system of assets that serve the public good. Infrastructure supports the functioning of society, and its operation and maintenance are necessary for the public's health, safety, and welfare. Infrastructure assets can cross jurisdictional boundaries, be held publicly or privately, and the benefits from these assets are generally available to a large portion of the population. They are held in public trust or their adoption is so widespread that social processes have become reliant on them. Some infrastructure is considered critical, i.e., so vital that its destruction or incapacitation would have a debilitating impact on the economy, security, public health, safety and welfare of society on a local, regional or statewide scale. The CSIWG's short definition of infrastructure encapsulates all of these points:

> **Infrastructure** is defined as the system of interconnected natural or human-made assets, as well as physical and virtual structures and facilities embedded in built and/or natural environments, that is put to social/economic uses, operated by humans, and governed by institutions, rules, social norms and expectations of their service.

Tangible examples of such infrastructure include (but are not limited to):

- **Transportation:** state highways (and connected transportation and transit systems, including rail lines and train stations) as well as all associated on- and off-ramps, signage, bridges, rest areas, office spaces and maintenance facilities;
- **Energy:** power generation plants, transmission lines, distribution lines and related equipment;
- **Criminal Justice:** correctional facilities, judicial branch facilities and crime laboratories;
- Water: water storage facilities such as dams, lakes and reservoirs, canals, pumping stations, hydroelectric powerplants, pipelines, levees and flood protection structures;
- **Natural Resources:** State parks and park-related facilities, fish hatcheries, constructed habitat, buildings and parking areas, CalFire facilities, and agricultural inspection stations;
- **Higher Education:** UC and CSU higher education campuses and community college campuses;
- **Health Services:** mental health hospitals and developmental centers; and
- **State Office Space:** State-owned or leased office structures used for governmental services[6].

Recognizing that the intent of the legislation was to provide recommendations to the State Legislature on how California could retrofit existing and create new climate-safe infrastructure, the CSIWG decided to limit their recommendations to only state infrastructure. "State infrastructure" was understood broadly, however, to include infrastructure that is:

- **State-owned:** State wholly or partially funds design and construction, operate, and maintains facility as State property;
- **State-funded:** State provides full or partial funding to another governmental body or utility; and

- **State-regulated:** State has regulatory oversight of non-government owned infrastructure elements that functions for the public good and are essential services, e.g., utilities.

The CSIWG also felt that their work and this report should serve as a model for how regional and local jurisdictions within California – as well as other communities and states across the nation and globe – could implement these recommendations for their own infrastructure design, planning, operation and maintenance. Thus, while many of the report recommendations are geared specifically to the California State Legislature and the State's SGC, they were also developed to be applicable to other interested communities. Overall, while the scope of this report is limited to state infrastructure and the impacts that state stakeholders can have on it, all the concepts discussed have relevance to the entire range of ownership and operation situations.

Disruptions from climate extremes are already commonplace now and will be an inevitable part of a climate-changed future. Thus, an important aspect of the CSIWG's conversations was agreeing on definitions of "resilience" and "climate-safe" infrastructure as these ultimately drive the CSIWG's recommendations.

Resilience is defined broadly as the capacity of an individual, community, organization, structure or environment and their associated human-made and natural systems to assess, prepare for, absorb, cope with, rapidly recover and learn from, effectively adapt to, or take advantage of, risks associated with shocks of adverse disruptive events and the stresses of continually changing conditions, including those associated with a changing climate.[4]

We have chosen this broad definition of "climate-safe" infrastructure and retained that label over potential alternative phrases common in current parlance (such as "sustainable" or "climate-smart") because of the ambition it conveys and because it is consistent with AB 2800.[5] Every scientific and infrastructure discipline has its own language, and debates over appropriate terminology are important and necessary. They should not detract, however, from the ultimate work at hand, which is to build a future that allows society, the economy and the natural environment on which we all depend to thrive, even in the face of change and disruption. As we will show throughout the report, "climate safety" is not a world free from change and disruption, but a world in which California has committed to seek the greatest possible safety for all of its residents through the best available knowledge, the best technology and engineering design, a strong workforce, and sustained political will and resources.

Climate-safe infrastructure is defined as infrastructure that is sustainable, adaptive and that meets design criteria that aim for resilience in the face of shocks and stresses caused by current and future climate. In addition, climate-safe infrastructure should be robust across a range of plausible climate and related socio-economic futures, as determined by the best available knowledge at the time the criteria (standards, codes and guidelines) are set. To remain "climate-safe," these criteria must be monitored and updated over time to account for changing conditions and the performance of resilience measures taken. Climate-safe infrastructure also reduces heat-trapping emissions to the maximum extent possible to not add to the climate change problem. (Mitigating climate change in this way also complies with California's emissions reduction targets.) Furthermore, climate-safe infrastructure addresses socio-economic inequities so that all groups in society increasingly benefit from safe, reliable and sustainable infrastructure.

Developing this Report: The Working Group's Process

With the very tight timeline following passage of AB 2800 that resulted in the appointment of the CSIWG, the State project team and co-facilitators established a formal process for:

- Engaging the CSIWG in the deliberations mandated by the legislation;
- Bringing in external expert voices to the discussion; and
- Developing a comprehensive webinar series to broaden discussion and provide an opportunity for public outreach about the legislation and the CSIWG's deliberations.

Below, we describe each in more detail to illustrate how much was accomplished in a very short time.

[4] We recognize that resilience has many different meanings to many different stakeholders. Even in the CSIWG, uses of this term differed. In this report, when specific types of strategies or interventions are discussed, the term resilience is used more narrowly but in conjunction with other strategies that together echo this comprehensive understanding delineated in this definition.

[5] Our definition of "climate-safe" infrastructure is close to what the ASCE defines as "sustainable" infrastructure.

Table 1.1: Overview of CSIWG Meetings

Meeting #	Dates	Locations	Primary Topics and Tasks	Subject Matter Experts Invited to Meetings
1	1/18/18	Sacramento	Launch of project; determine project goals; WG structure and process	**Secretary John Laird**, Natural Resources Agency **Hon. Bill Quirk**, California State Assembly **Jamesine Rogers Gibson**, Union of Concerned Scientists **Bruce Blanning, P.E.**, Professional Engineers in California Government **Deputy Secretary for Climate and Energy Keali'i Bright**, Natural Resources Agency
2	2/12/18	Los Angeles	Identify relevant infrastructure, sector-specific infrastructure standards, climate-sensitivity, information needs	**Sabrina Bornstein**, Deputy Chief Resilience Officer in the Mayor's Office, City of Los Angeles **Matt Barnard**, Principal Degenkolb Engineers
3	3/13/18	Bay Area	Linking forward-looking climate science and impacts information with standards, codes, certifications throughout infrastructure design/ implementation/ maintenance cycle	**Steve Reel, M.Eng.**, Project Manager, Port of San Francisco **John Thomas, P.E.**, City Engineer, City of San Francisco **Kit Batten, Ph.D.**, Climate Resilience Chief, PG&E **Bob Battalio, P.E.**, Chief Engineer, ESA Associates **Nate Kaufman, M.A.**, Landscape Architect, Living Edge Adaptation Project
4	4/11/18	Sacramento / Davis	Sector-specific design standards and cross-sector interdependencies	**James (Jim) Thorne, Ph.D.**, UC-Davis **Nicole Meyer-Morse**, Science and Technology Advisor, California Office of Emergency Services **Emily (Millie) Levin**, Policy Analyst, California Office of Emergency Services **Louise Bedsworth, Ph.D.**, Deputy Director, California Office of Planning and Research
5	5/9/18	San Diego	Governance of setting/ changing design standards; non-standard strategies to ensure climate-safe infrastructure; deliberation of draft report; agree on refinement needs	**Philip (Phil) Gibbons**, Program Manager Energy & Sustainability, Port of San Diego **Cody Hooven**, Chief Sustainability Officer, City of San Diego **Ralph Redman**, Manager of Airport Planning, San Diego Airport **Andrew Martin**, Senior Regional Planner, San Diego Association of Governments
6	6/20/18	Sacramento / Davis	Agree on final report revisions; delivery and outreach/promotion; project debrief and closure	**Beverly Scott, Ph.D.**, CEO, Beverly Scott Associates & Senior Partner, Parker Infrastructure Partners **Bilal Ayyub, Ph.D.**, Director, Center for Technology & Systems Management, University of Maryland

Working Group Meetings

Six Working Group meetings were held over the course of six months commencing on January 18, 2018 and ending on June 20, 2018. These were structured conversations that focused on a specific set of topics at each gathering. Meetings were highly interactive with the goal of eliciting as much knowledge, input and discussion among working group members as possible. The initial meeting was intended to focus and bound the CSIWG's discussions and goals. Meetings 2-4 focused on deliberation of topics determined through the goal and scope-setting accomplished in the first meeting. Meetings 5 and 6 focused on refining incomplete work areas and on the development of the report and its recommendations.

Meetings were open to the public and held in different locations across the state in order to provide opportunity for local engagement. To supplement the working group's discussions, each meeting involved local speakers who had subject matter expertise in the topics of each meeting (Table 1.1).

Webinar Series

To bolster the information included in the Working Group's deliberations, a webinar series at a frequency of 1-4 webinars per month was organized to run in parallel to the CSIWG meetings. The goal of these webinars was threefold:

- **Showcase CSIWG expertise** – to provide an opportunity for each CSIWG member to highlight their work and expertise;
- **Elicit input from outside experts** – to bring in outside expertise to address issues that were of interest to the CSIWG and its deliberations; and
- **Engage stakeholders** – to provide information to the interested AB 2800 stakeholders and to provide continuous updates of the work of the Group.

The webinars thus were by and for the Working Group but open to the public and usually had attendance rates of between 20-30 stakeholders in addition to the presenters. Most attendees were from within California, but some attended from federal agencies and outside California. The webinars were recorded and materials posted online. These webinars will remain on the CSIWG website and thus remain a resource to interested stakeholders in the future. Throughout this report, when relevant, we draw on and highlight webinar content that focused on relevant topics (Box 3, Appendix 2).

Box 3: The Climate-Safe Infrastructure Webinar Series (see also Appendix 3)

- **January 25, 2018 - Setting the Standards and Context: Federal to Local Roles**
- February 22, 2018 - Forward-Looking Climate Science for Use in Infrastructure Engineering: Possibilities and Limits
- **March 21, 2018 - Mobilizing the Future: Infrastructure Challenges and Opportunities in the Transportation Sector**
- March 22, 2018 - Rushing Toward the Future: Infrastructure Challenges and Opportunities in the Water Sector
- **April 6, 2018 - Green Infrastructure: Design and Integration for Climate-Safe Communities**
- April 10, 2018 - Governing Infrastructure: How Regulations, Standards, Codes and Guidelines Are Set and Changed
- **April 18, 2018 - Energizing the Future: Challenges & Opportunities in the Building/Energy Sector**
- May 15, 2018 - Building the Future: Challenges & Opportunities in the Building Sector
- **May 17, 2018 - Financing Climate-Safe Infrastructure I**
- May 29, 2018 - Financing Climate-Safe Infrastructure II
- **May 30, 2018 - Building a Climate-Safe Future for All: Social Equity and Inclusion in Infrastructure Planning**
- June 6, 2018 - Enabling Scientists and Engineers to Work Together Effectively
- **June 8, 2018 - Tools Supporting Climate-Safe Infrastructure Design**
- June 11, 2018 - Monitoring Infrastructure Performance
- **June 28, 2018 - Financing Climate-Safe Infrastructure III**
- July 12, 2018 - Communicating Climate Change – Reaching Skeptical Audiences
- **September 5, 2018 - The Findings and Recommendations of the CSIWG**

Table 1.2: Outreach During and After the AB 2800 Project

Date	Occasion / Audience
February 2018	Ann Kosmal, General Service Administration (GSA), on the CSIWG's purpose and process and relevant federal work on adaptation and resilience within the GSA
March 2018	Water Resources Adaptation to Climate Change Workgroup (per invitation of an AB 2800 webinar speaker, Dr. Kate White, US Army Corps of Engineers)
May 2018	ASCE Committee on Sustainability (per invitation by CSIWG Member, Dr. Cris Liban)
May 2018	Alicia Pegan, Climate Ready Boston Coordinator of the City of Boston, to share lessons about the CSIWG's process as Boston seeks to develop its own science-engineering working group
May/June 2018	Dr. Richard Moss, Columbia University, Sustained National Climate Assessment, to explore possible connections between the sustained assessment and California's efforts to improve science-application opportunities
June 2018	Dr. Kathy Jacobs, University of Arizona, regarding the panel of architects developing principles for climate-safe/resilient building design at the Global Climate Action Summit, San Francisco, in September 2018
July 2018	François Levesque, Infrastructure Canada, concerning communication challenges related to climate change and adaptation
August 2018	Presentation about AB 2800 and the CSIWG's process at a California Public Utilities Commission (CPUC) workshop on initiating a rulemaking proceeding on adaptation for electric and natural gas investor-owned utilities
August 2018	Presentation about AB 2800 and the CSIWG's process at a National Academy of Sciences workshop, "Making Climate Assessments Work: Learning from California and Other Subnational Climate Assessments"
August 2018	Presentation on AB 2800 and the CSIWG's report at the Third California Adaptation Forum, Sacramento, CA
September 2018	Report release via agency websites, AB 2800 webinar and news media
Post-Release (anticipated or confirmed outreach opportunities)	
October 2018	Briefing to the Strategic Growth Council
October 2018	Briefing to the California Legislature
Fall 2018	Dr. Doug Mason, Millennium Challenge Corporation, regarding the integration of climate considerations in federal international development work
Fall 2018	Briefing to Canada's Adaptation Platform Infrastructure and Buildings Working Group
Fall 2018	Presentation on the CSIWG's process, findings and recommendations to the Department of Homeland Security's National Infrastructure Advisory Council (NIAC), per invitation of NIAC Co-chair, Dr. Beverly Scott
December 2018	2018 Annual Meeting of the American Geophysical Union (AGU), paper proposed
January 2019	2019 Annual Meeting of the National Council for Science and the Environment (NCSE), session proposed, featuring CSIWG members
Spring 2019	2019 AGU Climate Solutions Conference, session proposed, featuring CSIWG members
Spring 2019	2019 National Adaptation Forum, session on infrastructure and social equity proposed

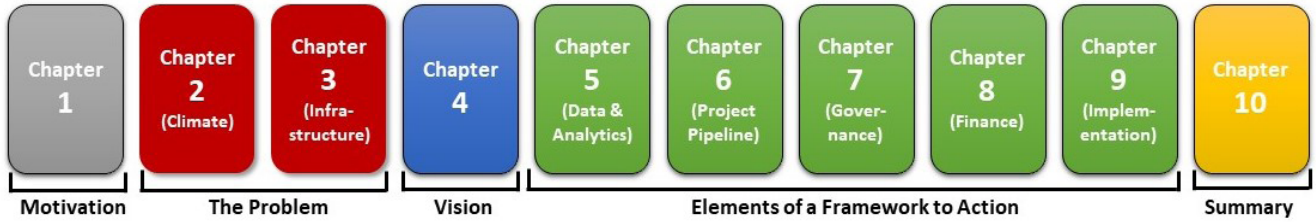

Figure 1.2 Report overview by chapter

Literature Review

Even though the incorporation of forward-looking climate science in engineering and architecture is a relatively new area of work, there is a growing body of literature that provides invaluable insight and best practices that will be relevant to California state engineers and architects as the state moves toward resilient and climate-safe infrastructure. In addition, there is a long history of state-wide and national efforts to design, improve, upgrade and modernize infrastructure across many different sectors. Working Group members also provided critical resources to inform the deliberations and the development of this report.[6]

Public Outreach

Early on in the process of the Working Group members urged to engage interested stakeholders to both educate the public about AB 2800, the necessity of building climate-safe infrastructure, and to provide an avenue for input into the Working Group's deliberations. We have accomplished this in a number of ways.

Through the AB 2800 Climate-Safe Infrastructure Webinar Series, the CSIWG was able to highlight some of their own work and expertise, as well as throughout the group's deliberations. In addition, the Co-facilitators gave a variety of presentations to various infrastructure and adaptation-interested audiences over the course of the project period (Table 1.2).

In collaboration with AB 2800 sponsors, CSIWG members, and interested stakeholder groups, outreach opportunities within and far beyond California (nationally and internationally) are continually sought and realized to ensure widespread awareness of the CSIWG's work and this report.[7]

[6] The reference list at the end of this report provides links to those accessible and/or free online.

[7] The co-facilitators in collaboration with the State agency project team and the Working Group developed an outreach plan. It is continually being updated to reflect opportunities. A summary of outreach will be prepared at the end of 2018.

Report Organization

Without even the complications of a changing and uncertain climatic future, California's infrastructure today is inadequately maintained and – in many instances – outdated[7]. With AB 2800 directing the formation of a Working Group of experts to inform its path forward, California has again proven its national leadership. It is taking stock of current infrastructure today, understanding how it may be impacted by climate change in the future and working to identify solutions and policies for planning for that future, starting today.

The goal of this report is to paint a vision and chart a path toward climate-safe infrastructure for all Californians – starting from where we are – and provide a set of strategic recommendations for how the State can realize this vision. We do so in nine chapters following this introduction, as described below (Figure 1.2).

Infrastructure design for the future must accommodate uncertainty to a greater extent than in the past. Dealing with this greater uncertainty in engineering will require some changes in engineering practice.

Chapter 2: Climate Change – The Challenge. California's climate is indisputably changing. This chapter describes the observed and projected changes in California's climate, provides a primer on the uncertainties associated with this information and how to interpret and assess those. It makes clear what is known with considerable scientific confidence and what is less well known, illustrating why infrastructure design for the future must accommodate uncertainty to a greater extent than in the past. Dealing with this greater uncertainty in engineering will require some changes in engineering practice.

Chapter 3: Infrastructure – The Starting Place. Chapter 3 provides an overview of California's infrastructure, sector by sector, including its current status, threats from climate change and opportunities to upgrade and modernize it. This baseline assessment sets the context for the discussion in subsequent chapters of how to retrofit and modernize the state's infrastructure systems.

Chapter 4: A Vision for Climate-Safe Infrastructure. Chapter 4 paints a vision for how California can develop climate-safe infrastructure. This vision entails continuing on the path of stringent emission reductions to minimize future climate change (mitigation) while planning the necessary adaptive pathways (adaptation) in case the global community fails to similarly reduce emissions. Such a failure would result in potentially grave risks to California, but the state can use a range of levers (policy, guidance, standards, funding, incentives etc.) to enact strategies that are flexible in practice but are targeted toward safety and infrastructure reliability. The vision outlined in this chapter makes equitable infrastructure investment a central motivation so that climate safety is realized for all Californians. The chapter also lays out an action-oriented framework of how to realize this vision; the elements of each are taken up in Chapters 5-9.

Chapter 5: Data and Analytics: Meeting Forward-Looking Science Needs. This chapter addresses one of the core mandates of AB 2800, namely the information needs engineers and architects have if they were to incorporate forward-looking climate science into infrastructure planning, design, construction, operation and maintenance. Because climate is not the only variable changing, the chapter also addresses non-climatic information needs to adequately plan for the future. Finally, the chapter addresses the question – asked in the legislation – what tools, platforms and processes are available or needed to facilitate interaction between scientists, engineers and architects.

Chapter 6: Project Pipeline: Pre-Development and Prioritization. Chapter 6 focuses on the all-important pre-development phase during which infrastructure projects go from concept to being ready for construction. We discuss the importance of effective and meaningful stakeholder engagement and introduce a number of tools and approaches that help with effective project design in the face of an uncertain climate future and other factors that project owners need to take into account. As the engineering and architecture community move into a new paradigm, novel design options are being introduced.

Chapter 7: Governance: Changing the Rules to Enable Climate-Safe Infrastructure. The traditional approaches to designing infrastructure are built according to prevailing standards, codes, guidelines and various non-standards-based approaches. In this chapter, we review how these standards and guidelines are set and identify which ones in California need to be updated to account for a changing climate. We introduce standards that are better suited to accommodate climate, describe efforts to translating these into practice and offer suggestions on how California can move forward in an era of changing standards and practices. We close with a discussion of institutional mechanisms needed to support the implementation of the systems-oriented, forward-looking and social equity-focused vision promoted in this report.

Chapter 8: Financing Climate-Safe Infrastructure. Chapter 8 reviews infrastructure funding trends, challenges, and the needs and opportunities to put in place finance systems that can make further progress on improving infrastructure finance in the state and address the potentially growing cost of infrastructure in the face of climate change. The analysis shows that in addition to climate science, demographic, land use and economic projections regarding future infrastructure needs, a variety of metrics of the environmental, social and governance performance of funding mechanisms and additional metrics to measure adequate progress and success of adaptive infrastructure projects are required to secure the necessary funding.

Chapter 9: Implementing Climate-Safe Infrastructure. In the final step in the framework to action, we explore some of the critical steps necessary for climate-safe infrastructure to be realized on the ground, including the need for: training, capacity building and workforce development, statewide coordination to support an integrated way forward with realizing the vision of climate safe infrastructure and concrete mechanisms for better linking state policy and guidance to project-level action or overcoming barriers that impede it.

Chapter 10: Summary: Barriers and Recommendations. We close the report in this final chapter by summarizing the barriers to moving toward climate-safe infrastructure and then summarize the recommendations that address them. Recommendations are grouped together under the headings of Chapters 3-8, thus mirroring the overarching vision and the core elements of the action-oriented framework. Together, the implementation of these recommendations will push California significantly forward on the path to realizing the compelling vision for climate-safe infrastructure across the state.

Figure 1.3 Developing climate-safe infrastructure requires the establishment of a strong bridge between science and the engineering community, as well as supportive public policy aligned with the goals of resiliency. (Photo: Bixby Bridge near Big Sur, CA; Russell Mondy, flickr, licensed under Creative Commons license 2.0)

Clarion Call

At its core, AB 2800 hones in on the critical need to establish the scientific foundation for wise infrastructure investment and planning. We fully support the commitment to evidence-based decision-making and forward-looking planning that this bill affirms.

But while developing climate-safe infrastructure will require the establishment of a strong bridge between climate science and high-quality design/construction/operation/maintenance of both physical and virtual infrastructure assets and facilities (Figure 1.3), a third – and overarching – pillar to realize the vision we lay out in this report is public policy aligned with the goals of resiliency and climate safety. This implies the need for reconsidering traditional stances and approaches to thinking about cost vs. investment.

Traditional thinking has it that building sustainable, climate-safe infrastructure costs more than traditional construction, designed typically to address only today's needs. Yet, in the second decade of the 21st century, when climate science is well established, failing to invest to protect those assets from climate change costs even more in the long run. Given the existing backlog and the need for new infrastructure, California cannot afford this added cost.

At most levels of government, as well as in the private sector, the general tendency is to put more emphasis on the initial outlay than on the long-term investment in the future of our state and the safety and well-being of our communities. It is understandable that – with limited budgets – decision-makers focus on building the most for the least. Yet we know that the initial construction cost is often only a fraction of the actual cost for maintenance, repairs and utilities. And that does not even consider the damages and losses – to structures and lives – when structures are built inadequately for the risks they will face over their lifetimes. And still, the pressure is to build at the lowest initial cost. Resilient and sustainable infrastructure do not come free, but costs can be minimized if relevant measures are built into projects from the start. Public policy must change if we are to build a sustainable future.