International Institute for Carbon-Neutral Energy Research

Hydrogen Materials Compatibility Roadmap Revision

February 2015

I²CNER, Kyushu University

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Division Objective

- Provide the basic science that enables optimization of the cost, performance, and safety of pressurized hydrogen containment systems.
  - Development and use of advanced tools (experimental and modeling) to identify fundamental mechanisms of hydrogen-affected fatigue, fracture, wear, and seizure in materials
  - Development of predictive performance models for materials subjected to hydrogen-affected fatigue, fracture, wear, and seizure
  - Development of next-generation monolithic and functionally graded materials having lower cost and improved performance (e.g., higher strength) while retaining resistance to hydrogen-induced degradation.

Division Projects, Objectives, Research Efforts

Projects	Objective	Research Efforts	Researchers
Project 1: Physical Descriptions of Hydrogen-Materials Interactions	Elucidate mechanisms and formulate physical descriptions for hydrogen-materials interactions and hydrogen-induced degradation in structural metals to inform alloy development and predictive crack propagation models	Develop and apply advanced tools (experimental and modeling) to characterize hydrogen-defect interactions and their relationship to hydrogen-induced material degradation Develop physical descriptions that relate hydrogen-defect interactions and degradation mechanisms to material characteristics at different length scales	Kubota, Matsuda, Kirchheim, Ritchie, Robertson, Sofronis, Somerday, Wang, Aravas, Nagao
Project 2: High-Strength, Low-Cost Stainless Steels for H_2 Service	Safe and reliable stainless steel H_2 containment components with reduced cost and weight without compromising performance in H_2	Dislocation hardening of lower-cost stainless steels through phase transformations Grain-refinement hardening of lower-cost stainless steels Microstructure-gradient hardening of lower-cost stainless steels through solution nitriding Development and application of advanced surface coatings as hydrogen permeation barriers	Takaki, Tsuchiyama, Nakada, Yamabe, Macadre

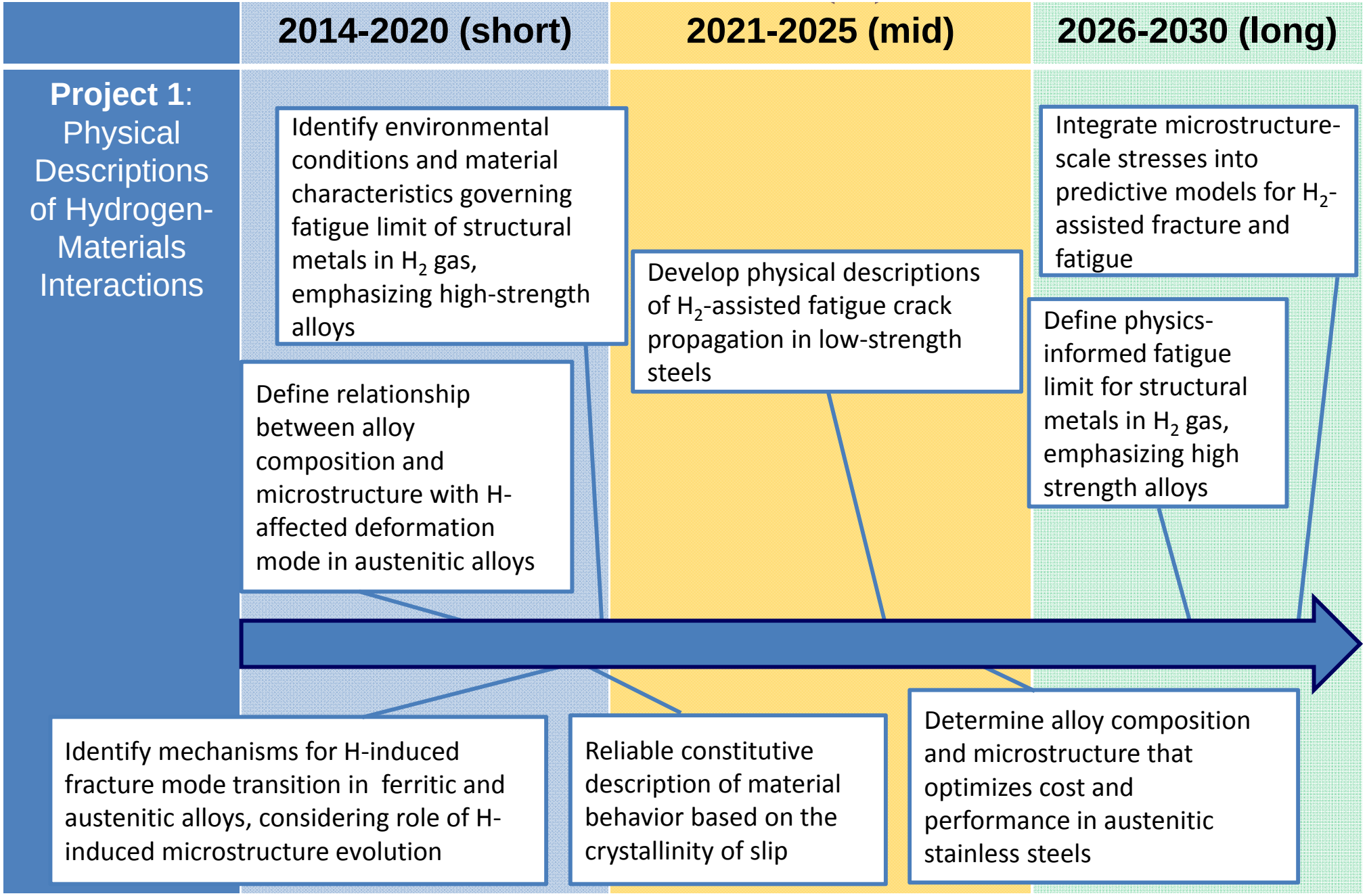
Division Projects, Objectives, Research Efforts

Projects	Objective	Research Efforts	Researchers
Project 3: Fracture and Fatigue Prognosis of Hydrogen Containment Systems	Improve safety and reliability as well as reduce costs by extending inspection and replacement intervals for high-pressure H_2 steel containment systems	Develop predictive models of time-dependent, hydrogen-assisted cracking that capture effects of material, environmental, and mechanical variables Enhance sensitivity and functionality of advanced sensors for monitoring service conditions and damage state of H_2 pressure vessels	Kubota, Ritchie, Sofronis, Somerday, Wang, Nagao, Xu

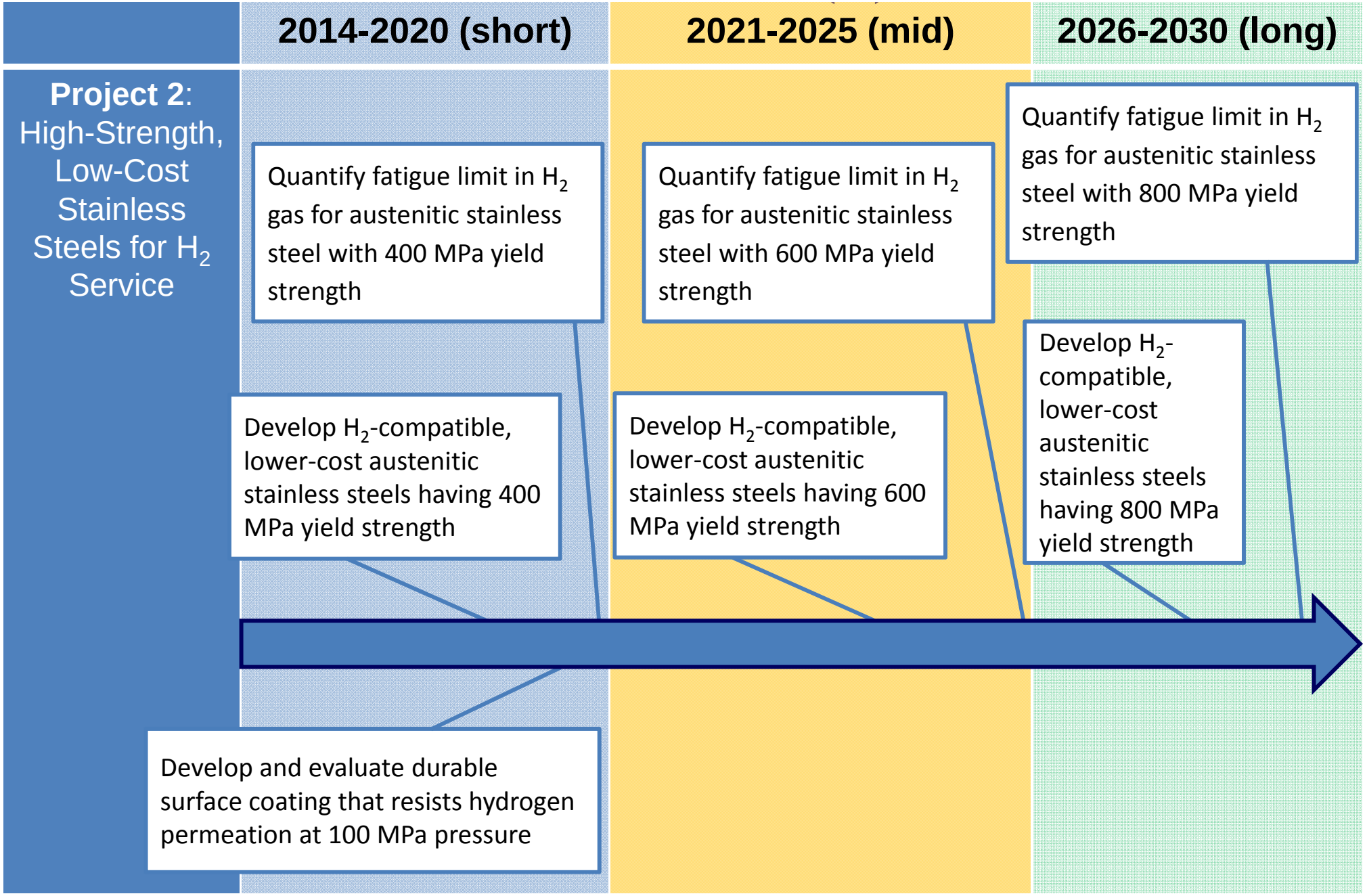
Division Projects, Objectives, Research Efforts

Projects	Objective	Research Efforts	Researchers
Project 4: Environmental Effects on Friction and Tribological Failures	Improve reliability of tribological components (prevent abnormal wear, adhesion, and seizure, extend rolling contact fatigue life) through fundamental studies of environmental effects on mechanical and chemical processes at tribo-interface. Improve efficiency of machines including H_2 energy systems by controlling friction.	Reduction of friction and wear of coatings and polymers Mechanics of seizure and lubrication relevant to failure (Particularly for IC engines) Mechanism of hydrogen-assisted tribo-failure and means to retard—wind turbines	Sugimura, Sawae, Tanaka, Yagi, Matsunaga, Morita, Yamaguchi

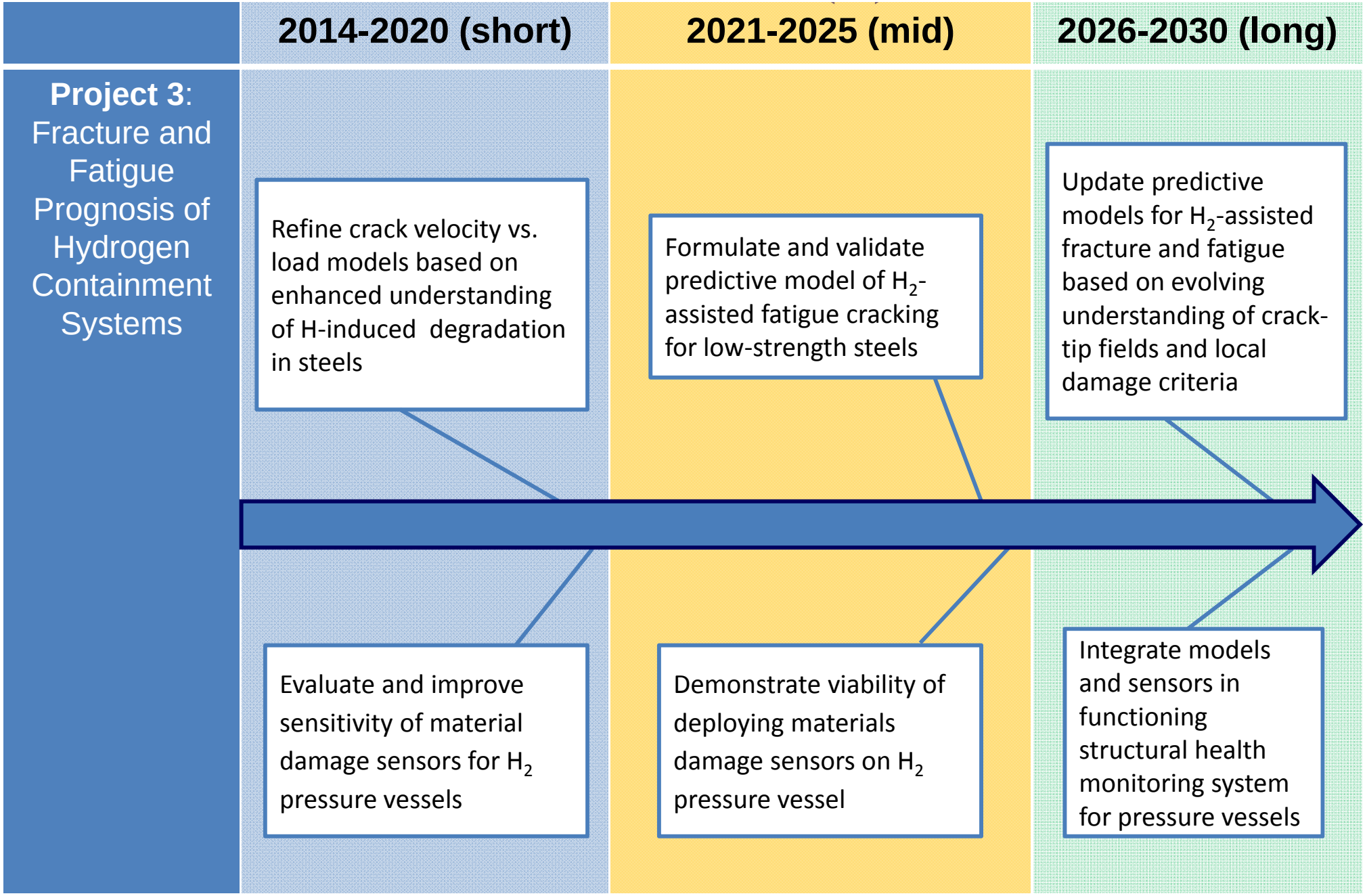
Milestones (1)



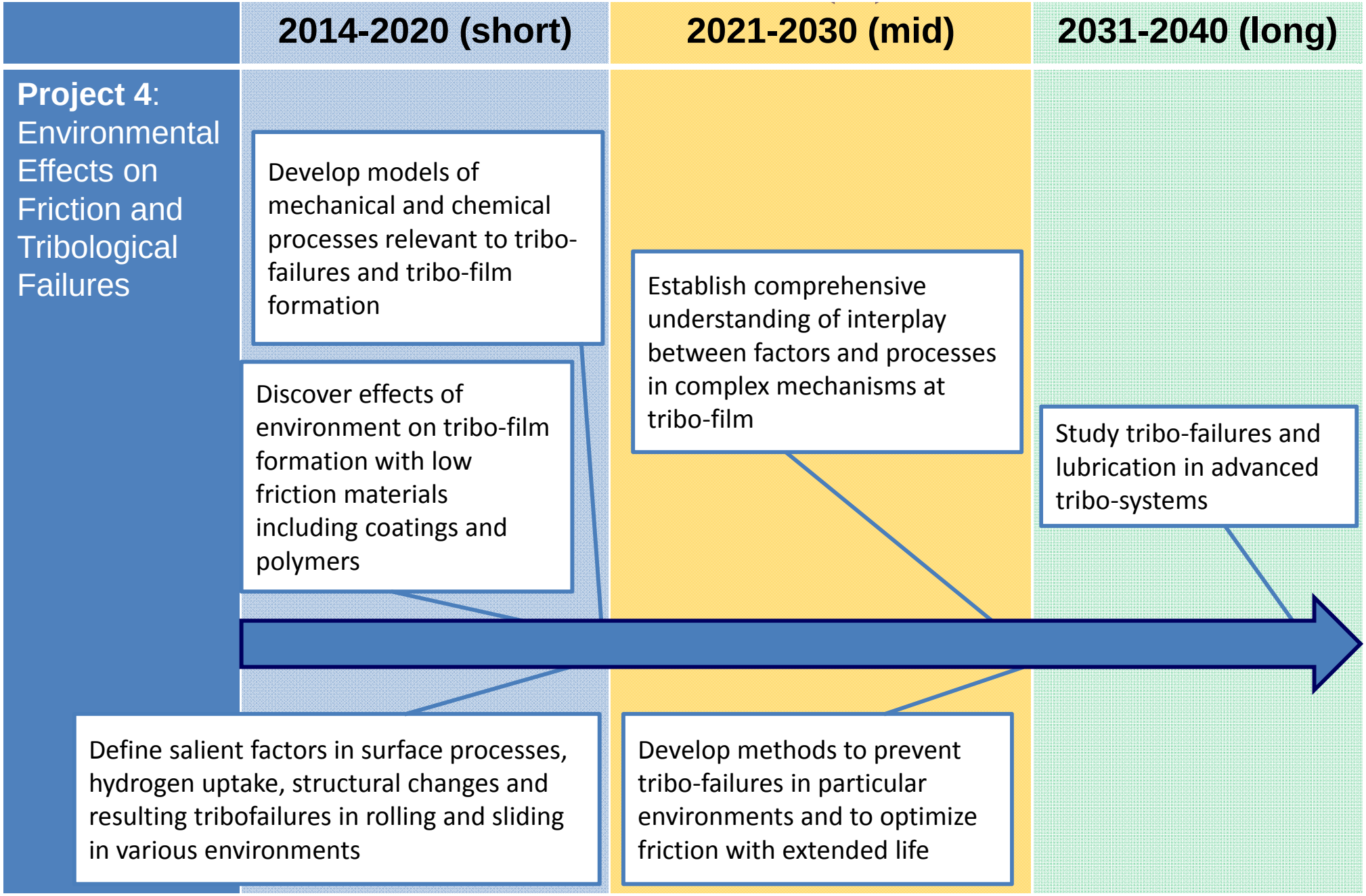
Milestones (2)



Milestones (3)



Milestones (4)



Ultimate Targets

	Current benchmark	Ultimate targets
Project 1: Physical Descriptions of Hydrogen-Materials Interactions	Experimental or modeling approach to study hydrogen-defect interactions or hydrogen-induced degradation mechanisms individually	Coupled experimental and modeling approach to define complete physical description of relationship between hydrogen-defect interactions and hydrogen-induced degradation
Project 2: High-Strength, Low-Cost Stainless Steels for H_2 Service	Baseline austenitic stainless steel for FCV or fueling station (i.e., SUS316L) has yield strength less than 300 MPa and higher cost than alloy 304	Alloy development: commercially viable austenitic stainless steel with strength comparable to ferritic steels (e.g., 800 MPa), cost-competitive with alloy 304, and acceptable durability for FCV or fueling station
Project 3: Fracture and Fatigue Prognosis of Hydrogen Containment Systems	Inspection frequency for Cr-Mo steel pressure vessels at hydrogen fueling stations is 1/year	Develop and integrate predictive crack propagation models and advanced sensors into structural health monitoring system to decrease inspection frequency for steel pressure vessels by more than 50%
Project 4: Environmental Effects on Friction and Tribological Failures	Empirical approach for design and materials selection of tribological systems	Physics-based predictive modeling approach for design and materials selection of tribological systems