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Dimensions of Hydrogen Safety

Preparing for Chaos

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Abstract

- **Focused on integrated approach to safety** by unpacking the layers involved and how CH_2SC plans to integrate the hydrogen industry currently scattered on safety aspects and implementation.
- **Levels of Safety Planning**:
  - **Level 1: Information layer**, on hydrogen basics – its properties need innovation and global effort.
  - **Level 2: Strategic layer**, plan for order vs prepare for chaos.
  - **Level 3: Analysis layer**, forecast apparent and non-apparent problems.
  - **Level 4: Design layer**, with inherent safety principles, layers of protection, etc.
  - **Level 5: Integration layer**, implement integrated systems to achieve robust safety during operations.
- **Introduction to the CH_2SC**:
  - CH_2SC is setup to help each customer in achieving these levels from start to finish and beyond.

Level 1: Information

Existing data on RCS, guidelines, good practices, etc.

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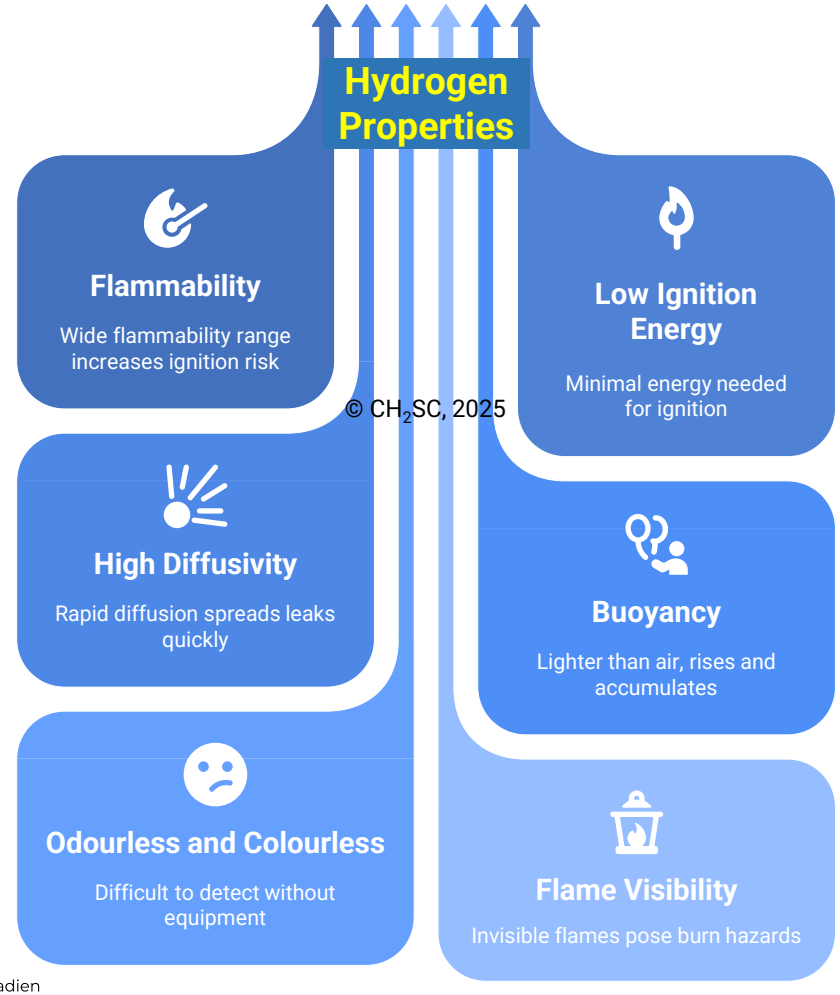
Need for Hydrogen Safety

Hydrogen's differentiating properties bring unique challenges to enable safe handling



Property © CH_2SC, 2025	Hydrogen (H2)	Methane (Natural Gas)	Gasoline Vapor
Flammability Limits (Vol. % in Air)	4.0 – 75.0%	5.3 – 15.0%	1.4 – 7.6%
Minimum Ignition Energy (MIE)	0.02 mJ	0.28 mJ	0.24 mJ
Density (Relative to Air)	0.07	0.55	3.0 – 4.0
Auto-ignition Temperature (°C)	585	595-650	258-280
Flame speed (m/s)	1.85 – 3.25	0.2 – 0.38	0.37 – 0.43
Energy density (MJ/m^3)	1.3	24.6	42.7
Colour	None	None	None
Odour	None	Added	Distinct
Combustion flame	Low-visibility	Visible	Visible

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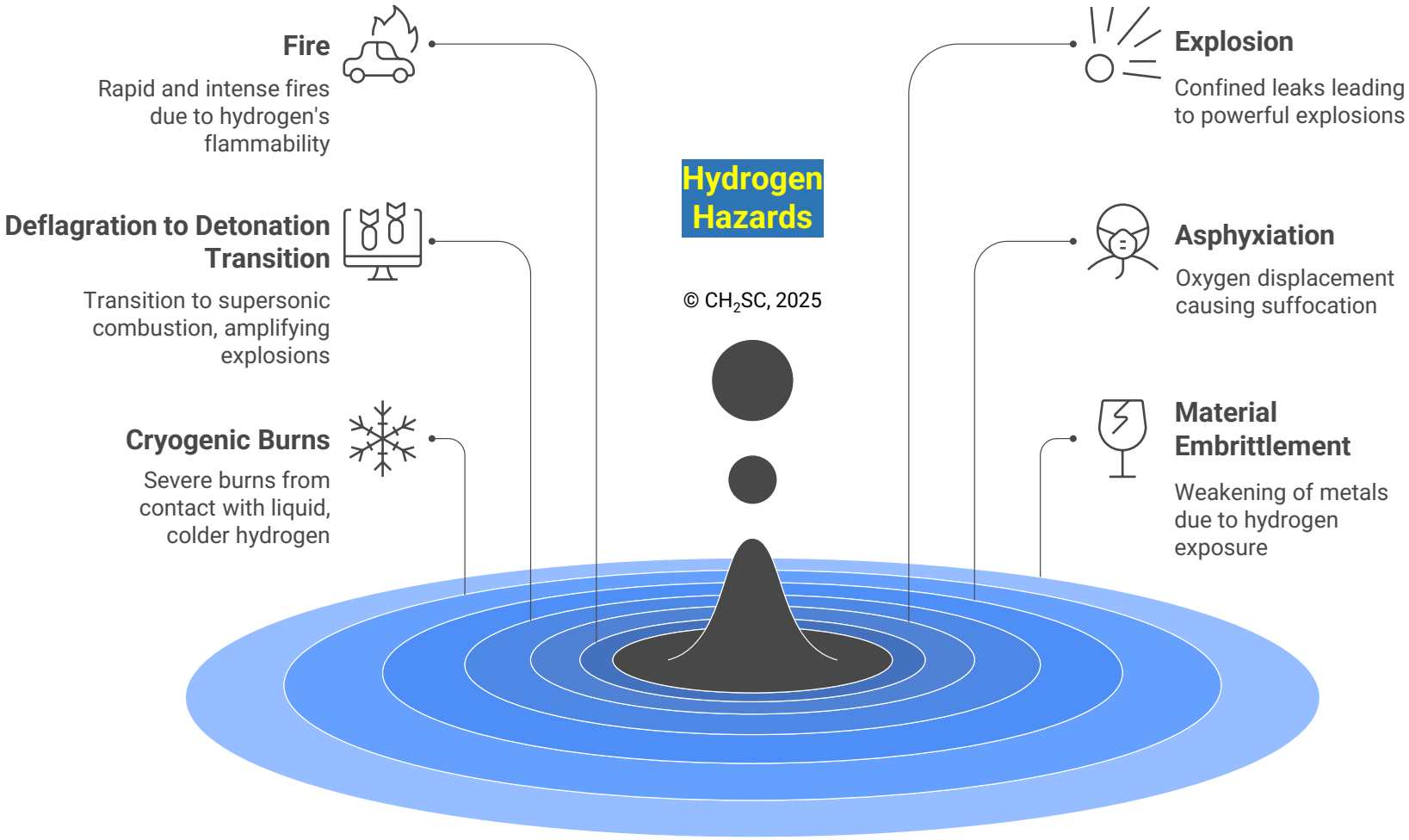
Hydrogen Safety Hazards

Significance in risks vary in different situations compared to other fuels



Hydrogen Safety Instruments

Key instruments from current standing

Hydrogen Safety Networks

More details on Level 1 of hydrogen safety planning can be found in many organizations

International and General Focus

- **International Association for Hydrogen Safety (HySafe):**
  - A non-profit organization focused on facilitating the safe adoption of hydrogen as an energy carrier by advancing safety measures and coordinating research efforts.
  - Emerged from a European Commission initiative.
- **Center for Hydrogen Safety (CHS):**
  - Affiliated with **AIChE** (American Institute of Chemical Engineers).
  - Provides guidance, education (including the Fundamental Hydrogen Safety Credential), and collaborative forums.
  - Maintains the **Hydrogen Safety Panel (HSP)**, which develops training content.
- **Safe Hydrogen Project (an initiative of the Compressed Gas Association - CGA):**
  - Focuses on developing and distributing safety information and standards for the production, storage, transport, and use of hydrogen globally.
  - The **CGA** itself has been developing gas and equipment safety standards, including hydrogen standards, for many decades.

Industry/Regional Associations

- **Safety Consultants:**
  - WHA International, Inc. a consulting firm, are leaders in hydrogen safety since 1988, with engineers from NASA and NREL.
  - Other notable consultants include: Jensen Hughes, Baker Risk, Gexcon, GTI Energy, etc.
- **Industrial Gases Associations (for regional safety frameworks):**
  - European Industrial Gases Association (EIGA)
  - Compressed Gas Association (CGA) (U.S. and Canada)
  - Asia Industrial Gases Association (AIGA)
  - Japan Industrial and Medical Gas Association (JIMGA)

Standards Development

- **NFPA 2:** The **National Fire Protection Association (NFPA) 2: Hydrogen Technologies Code** is a key standard, with leaders from other safety organizations (like CGA and WHA) serving on its technical committee.
- **ISO TC 197:** An international standards committee on hydrogen.
- **IEA Task 43**: Hydrogen TCP within IEA advancing RCS.
- **CSA Group**: Has more than 50 standards on hydrogen and helps harmonize standards with NFPA 2, CHIC, ISO, IEC, etc.

Level 2: Strategic Layer

Plan for order AND Prepare for chaos

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Planning vs Preparation on Safety

Preparation always beats planning; however, both are required depending on the timing and the need

PLANNING is based on the expectation of ORDER

Plan for order: the bridge gets destroyed by chaos

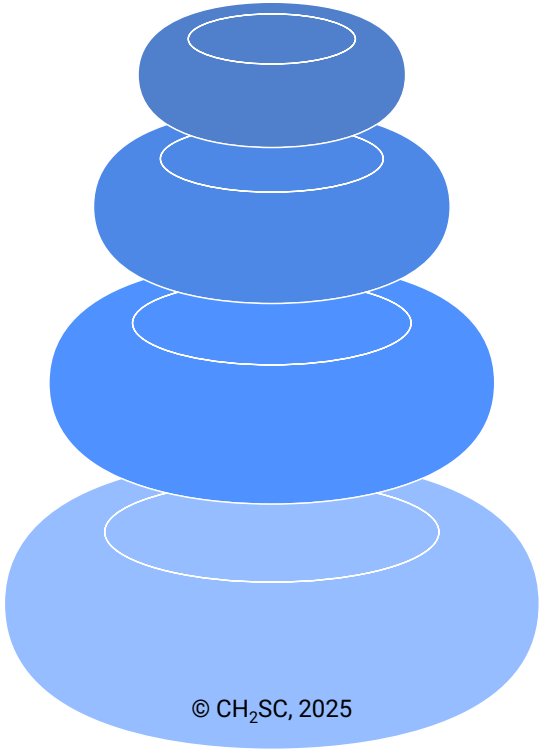
PREPARATION is based on the expectation of CHAOS

Prepare for chaos: the bridge thrives in most conditions

Strengths of Planning vs Preparing

Order and chaos coexists, hence focusing on the strengths at the strategic planning stage is vital

STRENGTHS: Planning for Order (Ideal for NOAK)



Measurable Progress

Easy tracking and adjustments against milestones

Control

Predictability and reassurance for teams

Clarity

Shared understanding of objectives and responsibilities

Efficiency

Optimized resource allocation and streamlined processes

STRENGTHS: Preparing for Chaos (Ideal for FOAK)

Resilience

The ability to withstand from beyond design basis

Adaptability

The capacity to adjust to new situations and conditions

Innovation

Approaching safety via inherent principles & innovate

Agility

The ability to respond quickly and effectively to change

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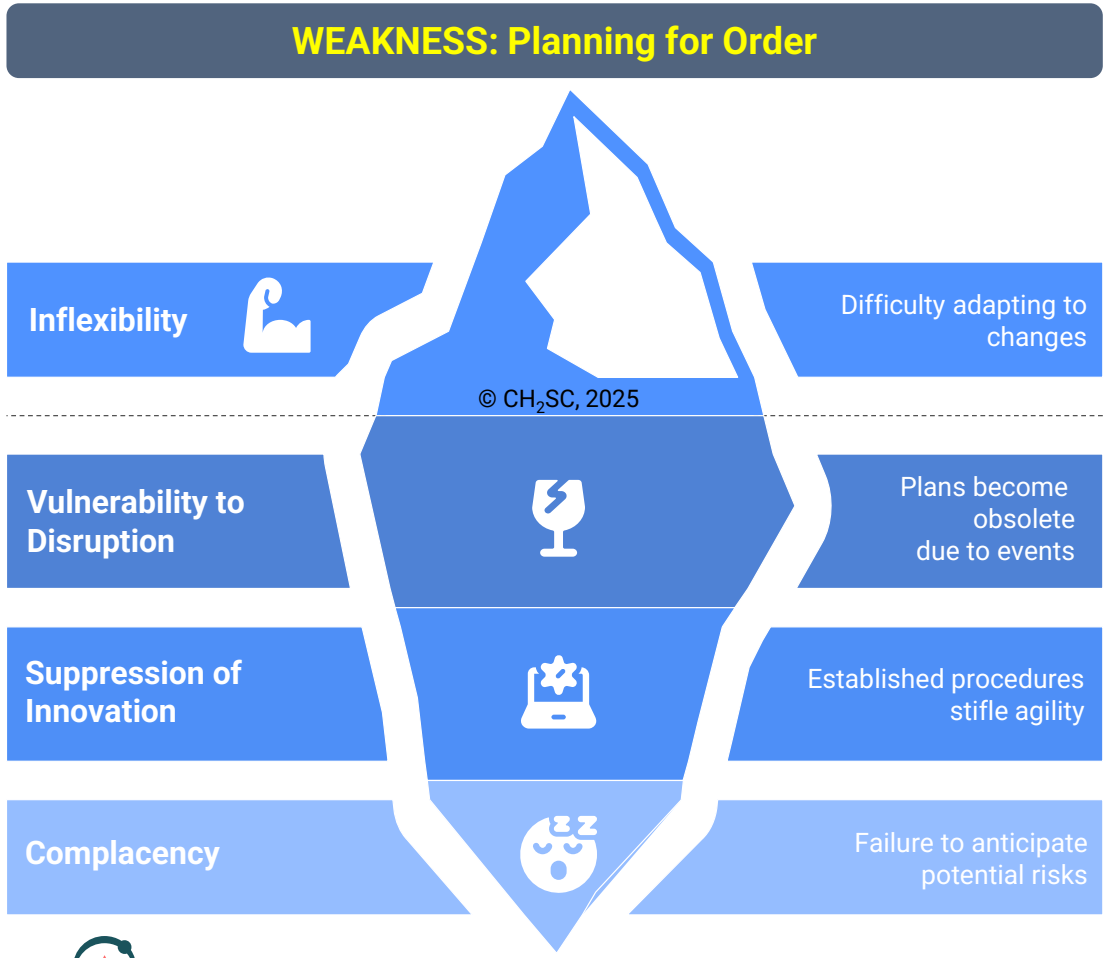
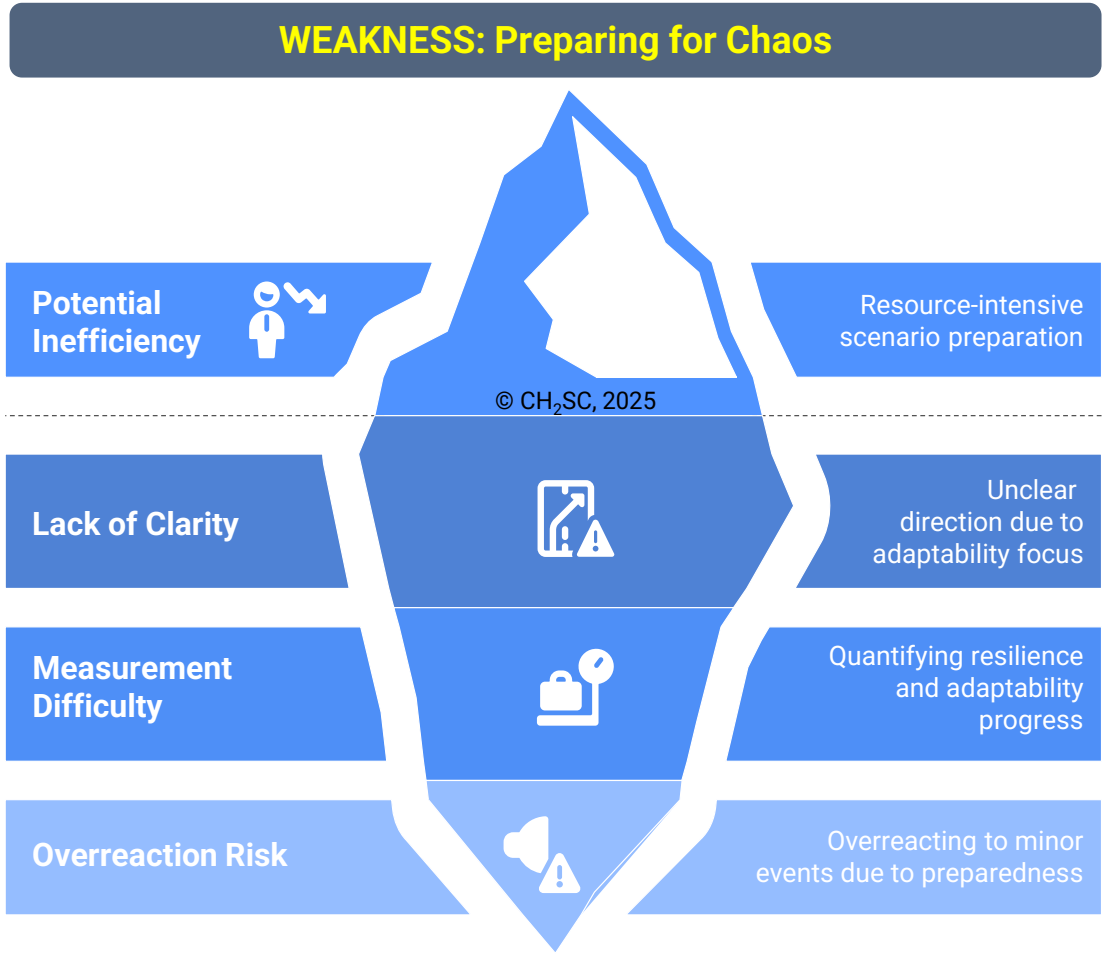
Weakness of Planning vs Preparing

Order and chaos coexists, hence focusing on the weakness at the strategic planning stage is also vital





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When to use Planning vs Preparing

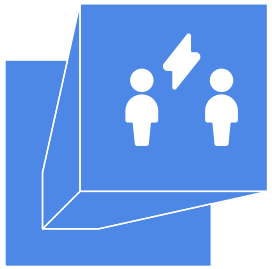
Order and chaos coexists, hence using them rightfully at the strategic planning stage is critical

USE: Planning for Order

Cost-Sensitive Projects

Where efficiency and cost control are paramount

Short-Term Plan

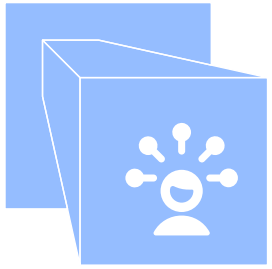


Plans with a clear scope and a limited timeframe

Routine Operations

Tasks or processes that are well-defined and repeatable

Stable Environments



Industries with a history of predictability & minimal disruption

USE: Preparing for Chaos

High-Risk Projects

Where the potential consequences of failure are significant

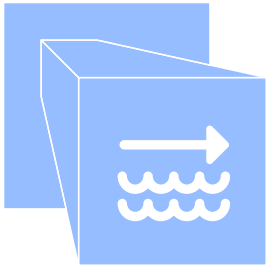
Long-Term Plan

Plans with long timeframe and a high degree of uncertainty

Innovation Driven

Focused on developing new products, services, or solutions

Volatile Environments



Industries characterized by rapid change, disruption, and uncertainty

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Level 3: Analysis Layer

Breaking down hydrogen work and activity structures

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Safety Risk Reducing Strategies

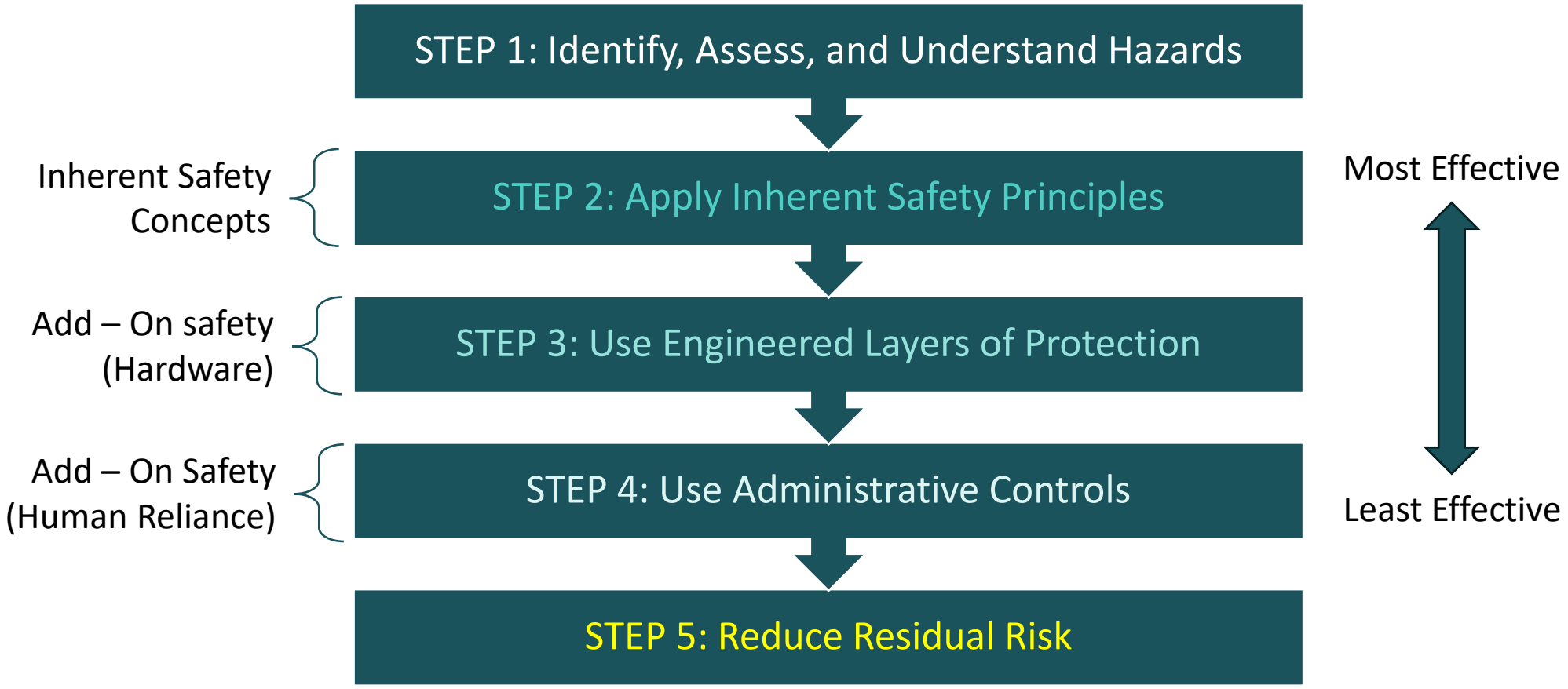
Toward reducing the frequency of risks or the consequences of potential risks

Most Effective and Optimal ← Expected Target ← **Effective and Required** ← Expected Target ← **Least Effective and Still Important**

Inherent Strategies	Spatial Strategies	Passive Strategies	Active Strategies	Procedural Strategies
Using non-hazardous materials	Use of distance to reduce the effects of hazards	Process design features (e.g. dike wall for tanks)	Safety controls, alarms, and interlocks (SCAI)	Policies, procedures, training, admin checks, ER, etc.
Using process conditions to eliminate hazard	Plant layout with separation distances	Equipment design features (e.g. intensify)	Mitigation systems to detect & respond	Human-process interfaces

Analyzing, Reducing, and Managing Safety Risks

Hierarchy of controls to reduce safety risks



Apparent and Non-apparent Problems

CH_2SC helps you prepare for safety, through analysis of design, codes and standards, operations, system boundaries, and other conditions, pertaining to any hydrogen system. An example is given below.

Preparation	Design	Codes & Standards	Operations	System Boundaries
Apparent Problems	• Inadequate design • Borrowed from non-hydrogen design • Wrong fundamentals	• Minimum requirements • Gap exists when application changes • Long development cycle	• Design failure • Dynamic operation • Safety device failure	• Cross-boundary interaction • Safe distances • Zoning principles
Non-apparent Problems	• Wrong technology • Improper design for hydrogen • Inadequate testing of component quality	• Safety data range • Adapting new safety technologies • Insufficient layers of protection	• Emergency situations • Insufficient operating mode • Feedback controls	• Interconnected boundary • Quality control • Safety device integrated networks

Level 4: Design Layer

Design of safety begins with design of hydrogen systems

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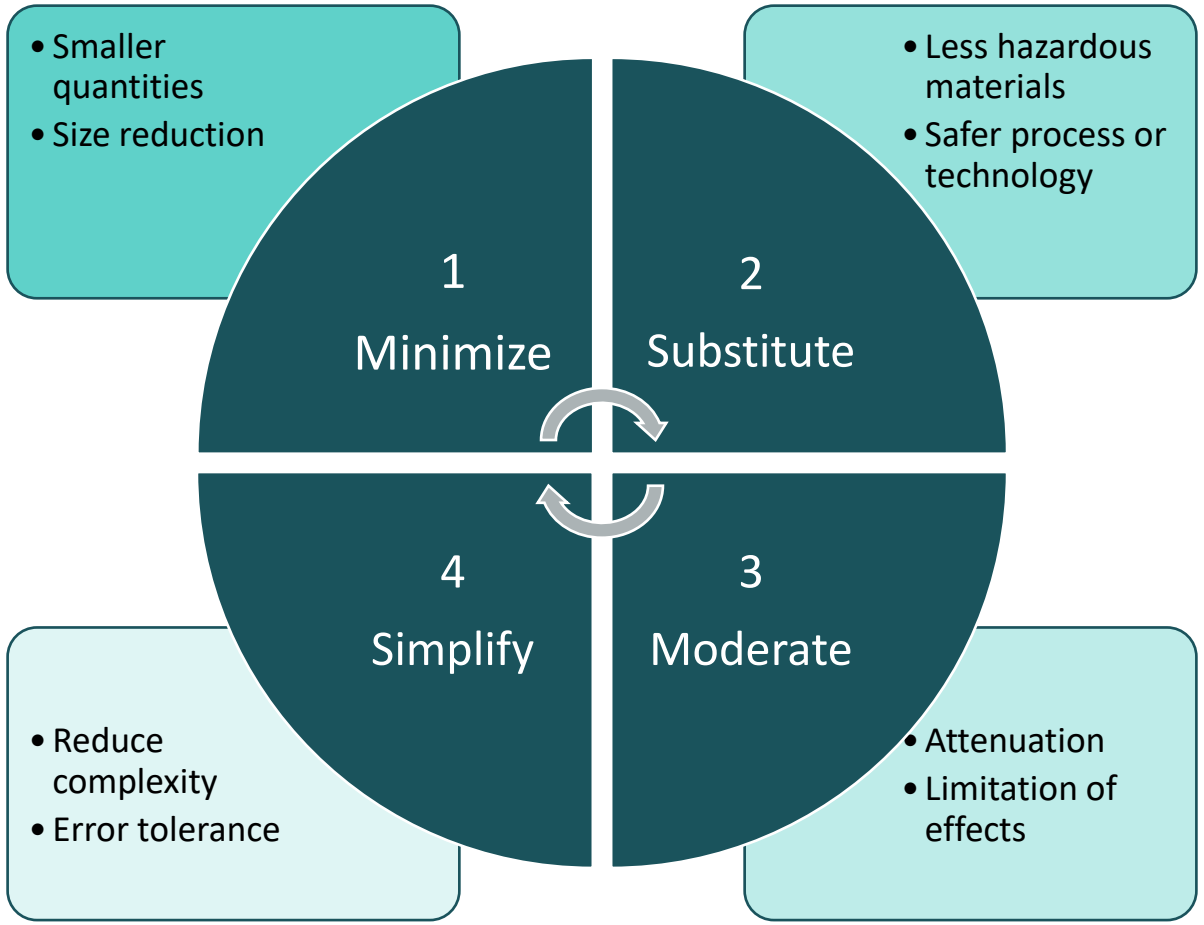
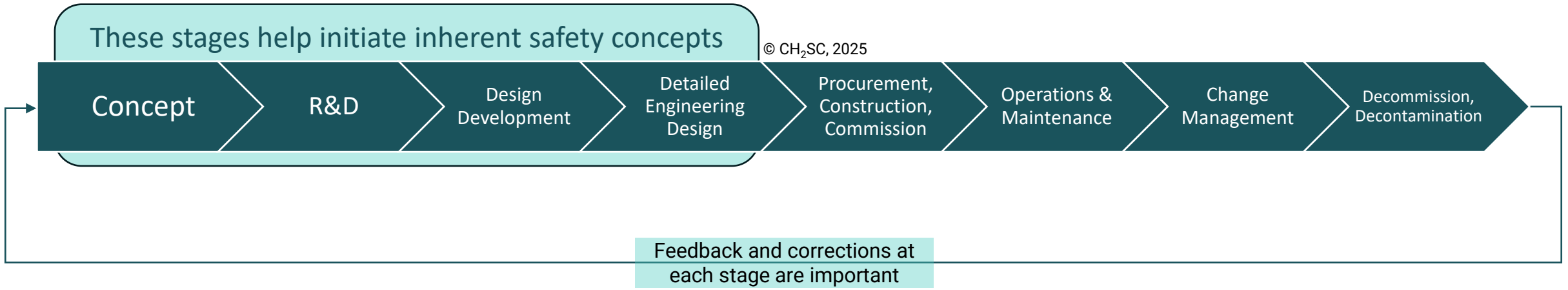
Inherently Safer Strategies/Principles

Applies to each stage of the hydrogen process or plant safety lifecycle



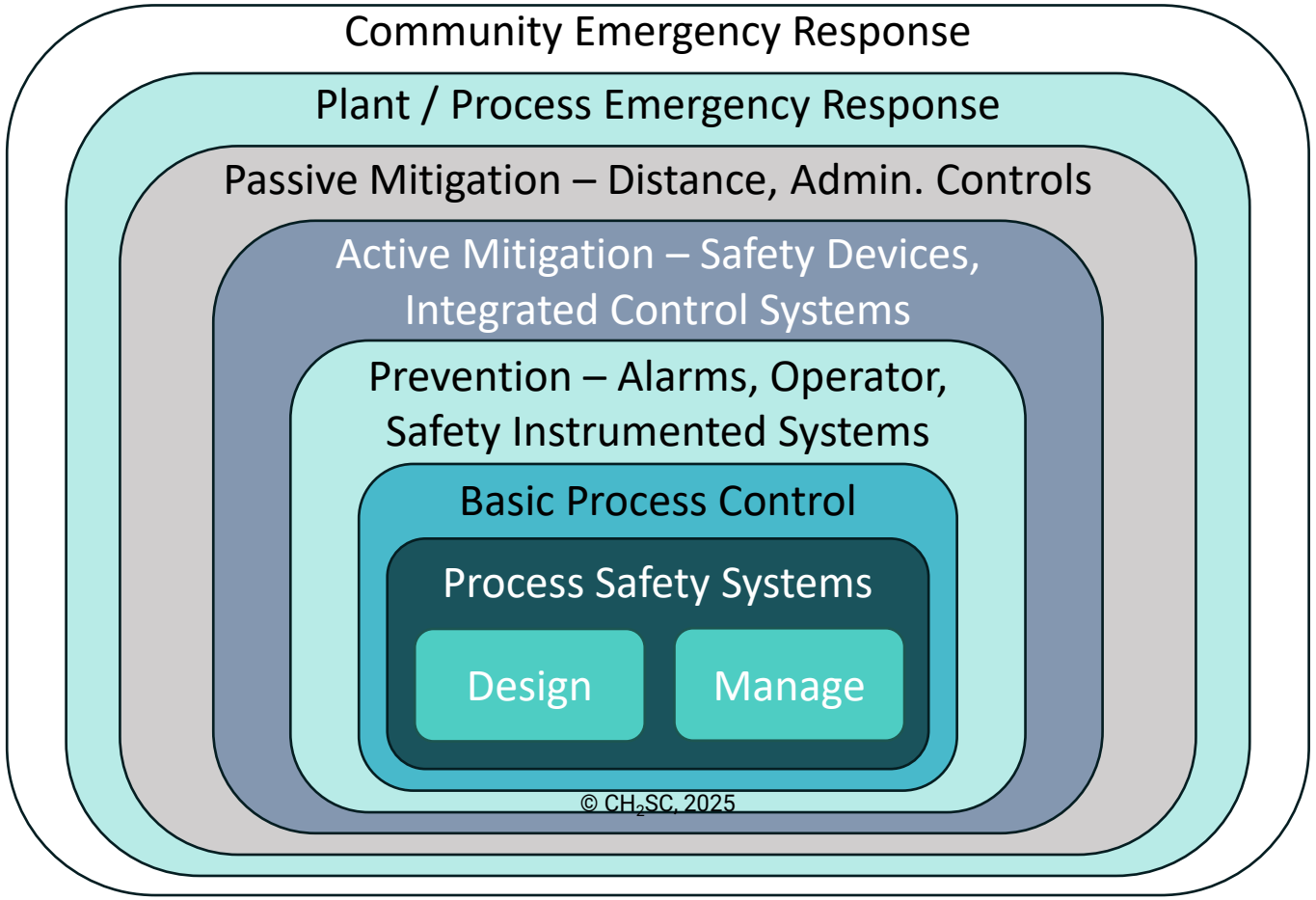
Hydrogen Plant Stages for Safety Lifecycle

Each stage represents a unique set of risks that needs minimizing through inherent safety concepts



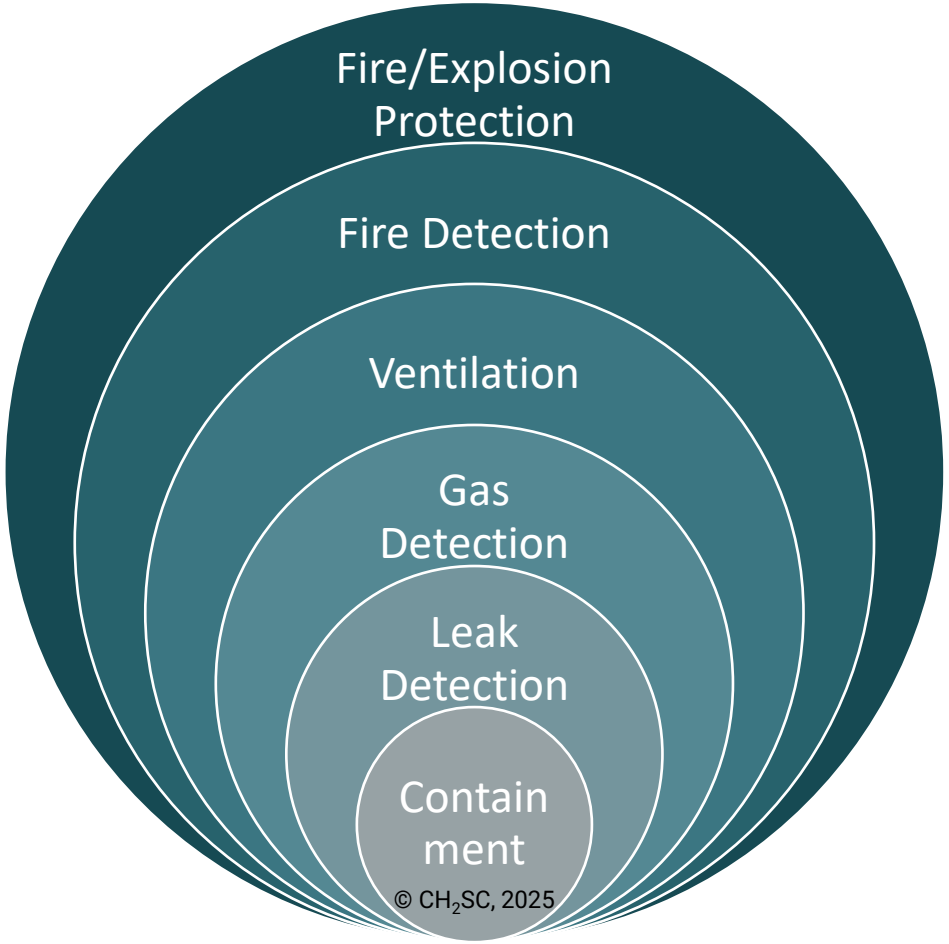
Interlinked Layers of Protection

Layers are often interlinked to improve safety



Integrated Layers of Protection

Layers are often integrated through control systems



Level 5: Integration Layer

CH_2SC primary role is to standardize integrated approach

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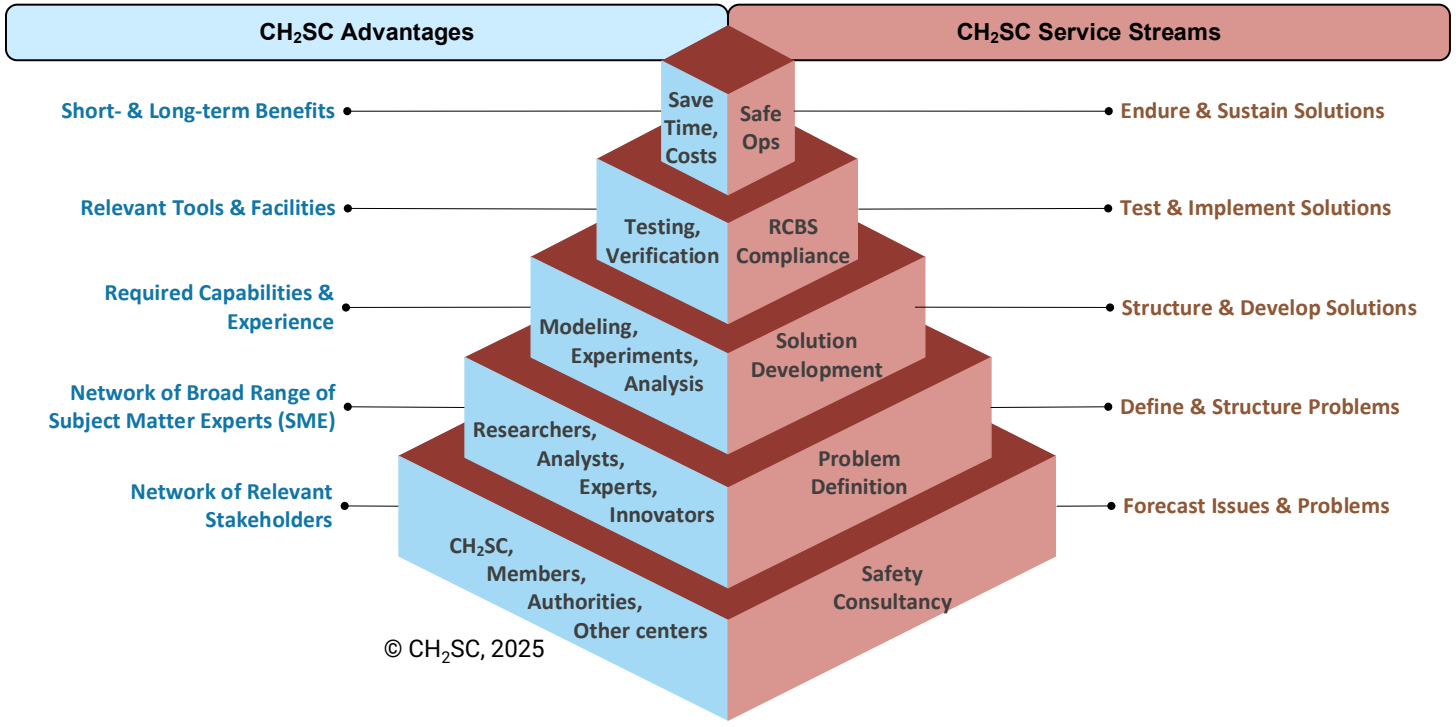
CH_2SC Approach to Solving Safety Problems

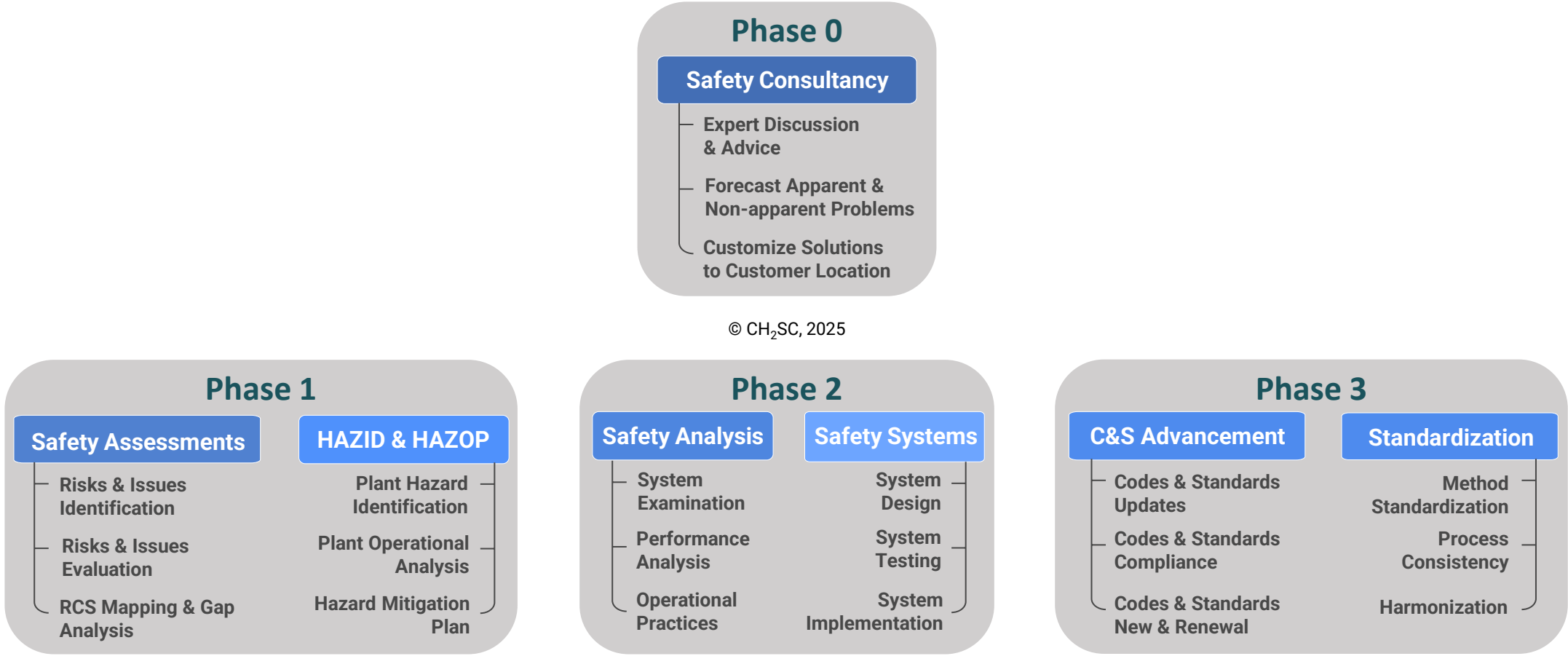
Integrated approach to safety solutions starting with consultancy and engagement

- Starts with activities from the bottom of the pyramid
- After defining the problem, existing solutions would be explored prior to embarking on solution development
- Help achieve safe operations



CH_2SC Safety Preparation Phases

Services offered by CH_2SC are grouped into phases of work activities, this is an example



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CH_2SC Safety Integration Example

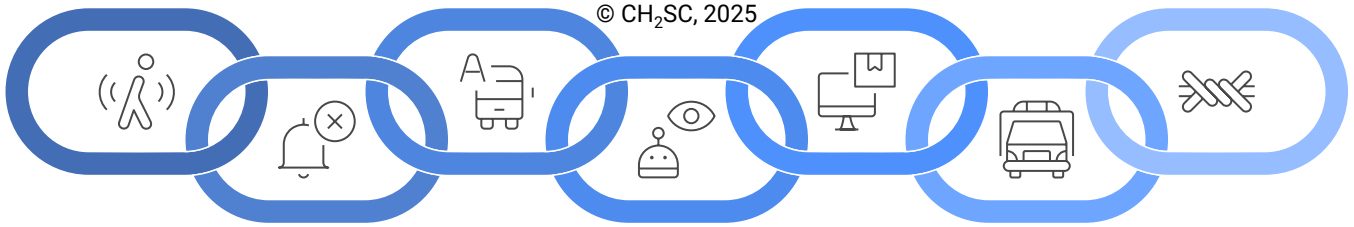
Safety technologies and instruments are integrated based on each hydrogen application and scenario

High-sensitivity Detectors & Sensors
Advanced sensors that detect hazards with precision

Integrated Control Systems
Centralized systems that manage and coordinate safety operations

Realtime Inspections
Continuous monitoring and assessment to ensure safety standards

Cascaded Barriers
Multiple layers of protection to prevent incidents from escalating



Mitigation Devices
Tools and systems designed to reduce the impact of safety incidents

Situational Aware Technologies
Technologies that enhance understanding of the environment for safety

Integrated Emergency Response Systems
Coordinated systems for quick and effective response to emergencies

About CH_2SC

A Not-for-Profit Company

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Canadian Hydrogen Safety Centre (CH_2SC)

Mission:

Deliver **tangible hydrogen safety solutions**, across multiple industrial sectors and regions, for apparent and non-apparent problems

Objectives:

- **Forecast safety problems** and prioritize activities to align with each industrial sector reliant on hydrogen-based processes
- **Coordinate** Canada's hydrogen safety expertise and capabilities to enable hydrogen projects and support industrial needs
- **Support the development, advancement, implementation** of codes, standards, bylaws, and regulations
- **Enable access** to experimental infrastructure, test facilities, and safety expertise for problem solving and to sustain safety
- **Serve in an advisory capacity** to governments, regulators, policymakers, and industry on safety issues, events, and solutions

Purpose:

To **coordinate activities** to address safety problems; to **lead actions** to establish relevant safety levels; and to **strategize plans** for continued safe operations with each application and use-case for hydrogen

CH_2SC Structure

Not-for-profit at its core

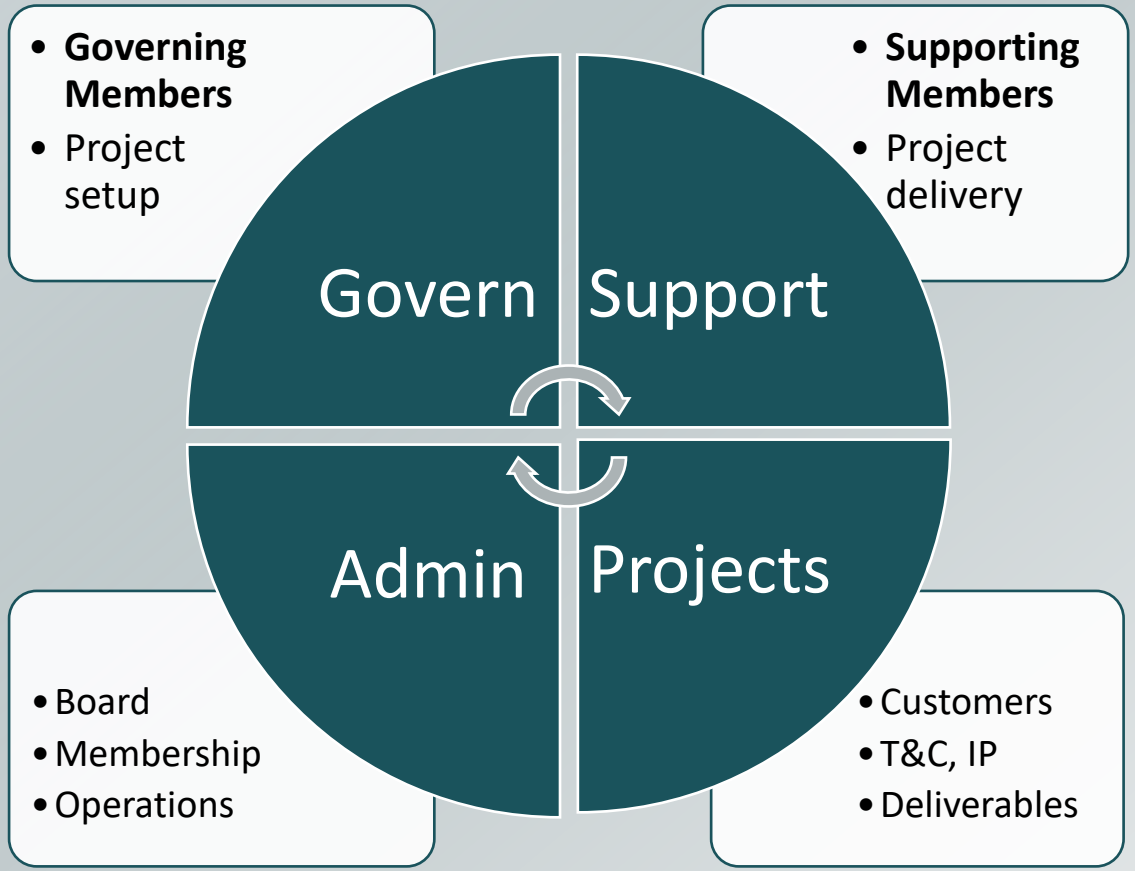
Corporate Structure

- *Board of Directors*
- *Officers*
- *Members*

- *Committees*
- *Program areas*
- *Projects*

- *Partners*
- *Customers*
- *Advisors*

Governance Structure



CH_2SC Leadership and Management

Each team member has significant experience in their respective areas and to guide the Centre

Board of Directors

Peter Elder
Canadian Nuclear Laboratories, Ontario, Canada

Brian Wagg
C-FER Technologies, Alberta, Canada

Bruno Pollet
Université du Québec à Trois-Rivières, Québec, Canada

Mikaa Blugeon-Mered
La Mosaïque Hydrogène, Paris, France

Stuart Hawksworth
Health & Safety Executive, Buxton, UK

Officers

Nirmal Gnanapragasam
President/CEO, Ontario

Steven McGee
Projects Director/CPO, Ontario

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CH_2SC Safety Ecosystem

Enhancing safety as a community

Research-Driven Innovation

New technologies from joint efforts

Industry

Drives practical technology development

Academic Institutions

Generates foundational research and knowledge

Safe Commercialization

Compliant and reliable products

Policy-Informed Research

Research aligned with safety frameworks

Authorities

Sets safety standards and regulations

CH_2SC Corporate Responsibilities

Network of experts in each layer working together to enable hydrogen safety

President, CEO, CPO, COO

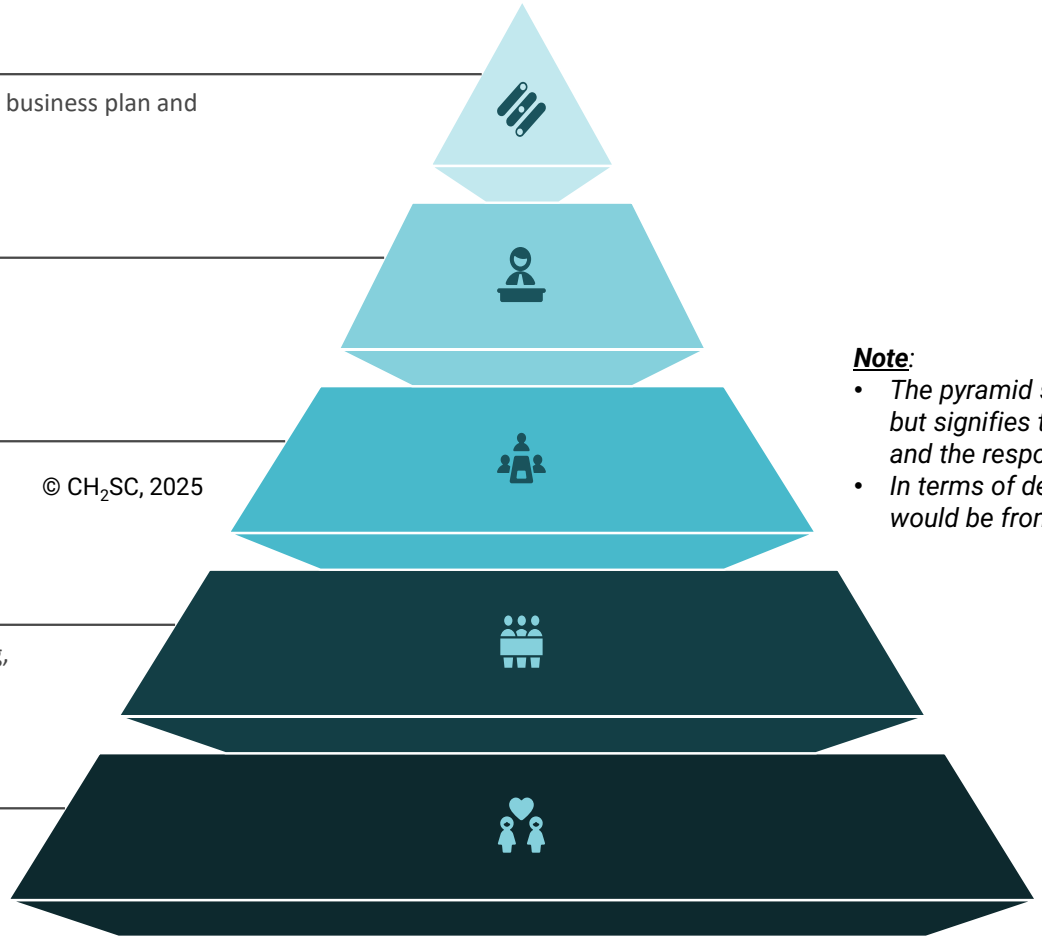
Manages daily operations, executes the business plan and delivers on the strategic vision

Board Chair

Leads the board and ensures effective governance

Board of Directors

Ultimate decision-making and approval authority



Governing Members

Oversee organizational policies, funding, and direction

Supporting Members

Provide essential support and technical resources

Note:

- *The pyramid shape does not refer to a hierarchy but signifies the number of experts in each layer and the responsibility.*
- *In terms of decisions and actions, communication would be from bottom to top and top to bottom.*

CH_2SC Membership Classes

Member categories are setup to help different industrial, research, and academic groups to join

Category	GOVERNING MEMBER CLASS
INDUSTRY	• Hydrogen handler (produce / store / use) • Requires ongoing support • Plans for hydrogen use in new applications • Fee starts at $50,000: 1 board seat
INVESTOR	• Investor in the Centre's value to industries • Supports operations and enables safety • Benefits through tax reduction & ESG ratings • Fee starts at $100,000: 1 board seat

Category	SUPPORTING MEMBER CLASS
TIER 1	• Larger organizations with project delivery experience • Brings deep safety expertise & experience • Ideal for engineering, services, safety firms • Staff: >30 | Revenue: > $1 million/year • Fee starts at $10,000
TIER 2	• Mid-sized organizations with project delivery experience • Brings safety expertise and experience • Ideal for universities, specialist, niche, boutique firms • Staff: 10-30 | Revenue: $0.5-1 million/year • Fee starts at $5,000
TIER 3	• Smaller organizations with project delivery experience • Brings specialists, experts, & researchers • Ideal for start-ups, consultants, small OEMs • Staff: <10 | Revenue: < $0.5 million/year • Fee starts at $1,000

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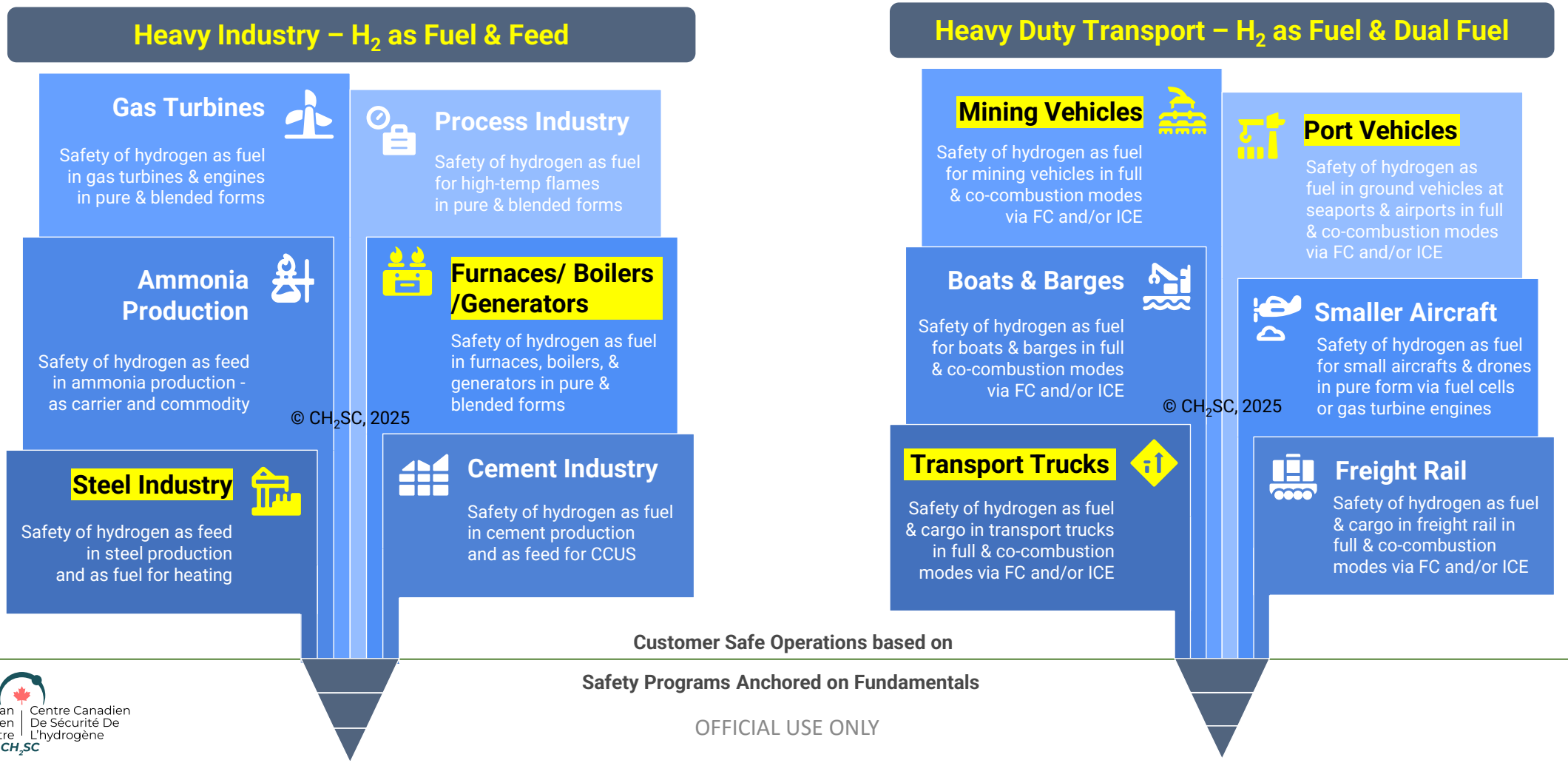
CH_2SC Safety Programs

Programs help to group R&D work and deliver collective outcomes and sequence long-term effort



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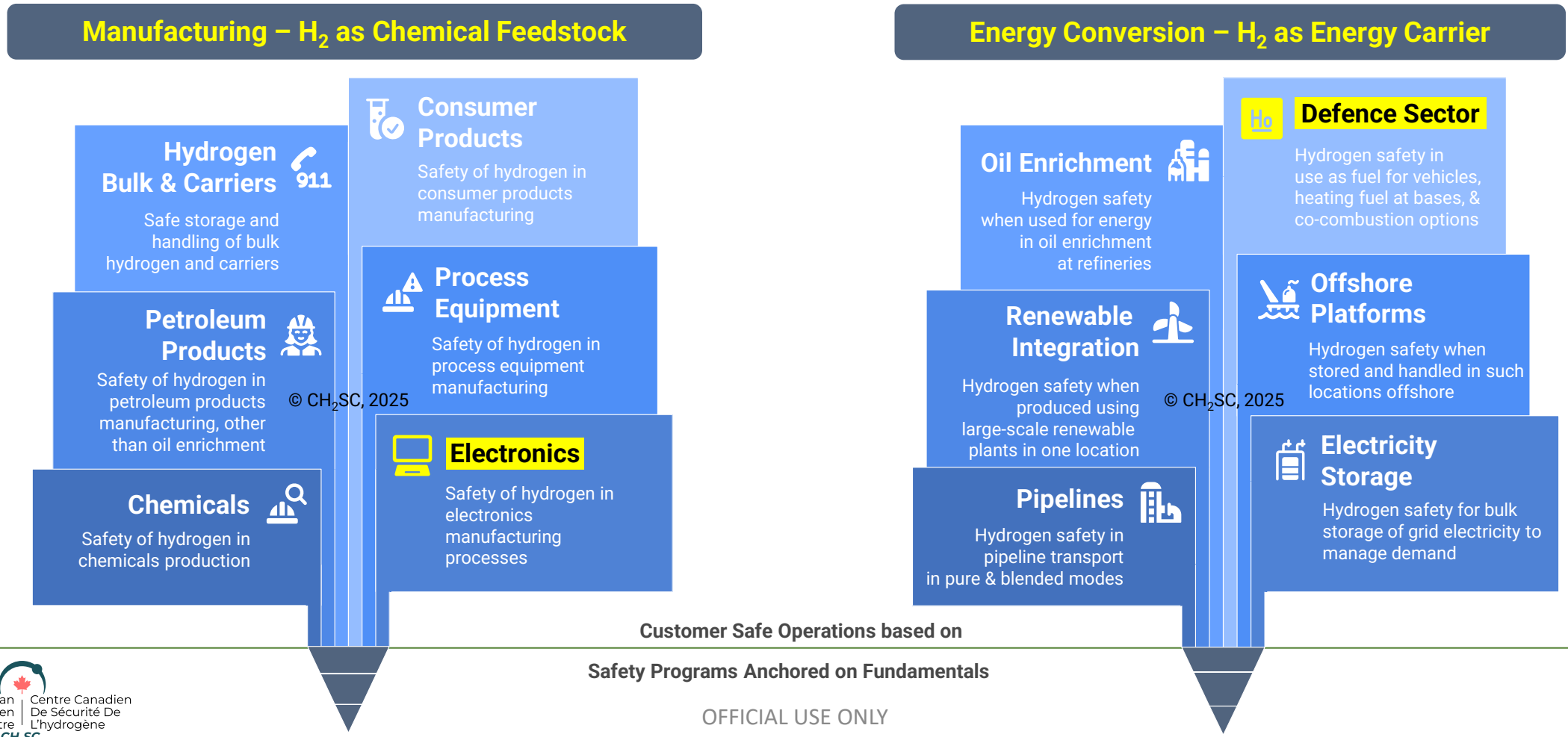

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CH_2SC Safety Products

Products are to be developed as templates and to be customized for each customer

Roadmap to Licensure

A plan outlining the steps to obtain necessary licenses for hydrogen plants

Safety Cases

Documents presenting evidence that a system is acceptably safe

Risk Mitigation Plans

Strategies to reduce the likelihood and impact of potential risks

Safety Costing Models

Tools to estimate the expenses associated with safety measures

Safety System Protocols

Standardized procedures for ensuring safety within a system

Safety Test Data

Data from safety tests from internal and external projects to evaluate safety

Safety Simulation Models

Computer programs that simulate safety scenarios to predict outcomes

Safety System Implementation

The process of putting safety systems into practice & testing

Safety Devices

Physical tools and equipment designed to enhance safety via integrated layers

Safety Guidelines

Recommendations and best practices for maintaining safety

Thank You

Contact the Officers of the CH_2SC:

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