Our **fourth HYDROGEN Seminar** on October 11, 2022 at KAUST reviewed hydrogen safety and transportation.

Nick Barilo gave an overview of hydrogen safety and discussed its unique hazards, as well as specific mitigations. For example, hydrogen's high buoyancy promotes its diffusion up and away from a leak, but hydrogen also has a wide flammability range and a high flame velocity that facilitates its detonation. However, Mr. Barilo pointed out that hydrogen has been used by industry for more than a century, so expertise and best practices for its safe use are already well established. He stressed that we must all be proactive to prevent incidents that can potentially cause harm and result in industry setbacks, while human error is the common thread in almost all hydrogen incidents. Mr. Barilo stressed that safety planning is critical for every project with attention to the basics, including a selection of materials, system integrity, active ventilation, leak detection and isolation, discharge management, and emergency shutdown. Regulations, codes and standards, best practices, personnel training, communication and strong safety culture are all key. Therefore, dangerous assumptions, misconceptions, apathy, and fear should all be avoided. The Center for Hydrogen Safety is developing a community to promote hydrogen safety and offers free training resources (h2tools.org).

Prof. Mani Sarathy discussed hydrogen transportation and storage. Prof. Sarathy first gave the advantages and disadvantages of using compressed or liquid hydrogen. For example, compressed hydrogen ($cH_2$) is stored onboard vehicles at 350 or 700 bar in carbon-fiber wound "Type 4" tanks. Demand for carbon fiber for this application requires the industry to scale up production. Grid-scale storage of high-pressure gaseous hydrogen will likely be in underground pipes or caverns. The transportation of bulk gaseous hydrogen is challenging due to its low volumetric energy density, therefore, liquid hydrogen (LH2) is often used. However, the liquefaction of hydrogen is energy intensive and it must be stored in large spherical vacuum-isolated tanks. LH2 also boils off but this could potentially be used to power the transport vessel. Furthermore, new LH2 transport vessels (ships) and LH2 storage facilities at ports would have to be built for large-scale transport of LH2. Pipelines are another option for transporting gaseous hydrogen long distances, but they are expensive. As a case study, Prof. Sarathy described a hypothetical hydrogen pipeline from NEOM to the port at Yanbu. Alternative forms of physical and chemical hydrogen storage are also being developed. Examples include metal hydrides, ammonia, and liquid organic hydrogen carriers (LOHC) such as dibenzyltoluene (DBT). Ammonia is a promising candidate because the tankers and port infrastructure already exist at ports around the world. However, both ammonia and LOHC require systems (and energy) to extract the hydrogen, and in the case of LOHC, the carrier must be shipped back to its origin for rehydrogenation.

Dr. Tim Allison focused specifically on hydrogen transport in pipelines and their associated infrastructure consisting of mechanical equipment such as compressors. A study showed that transporting energy in the form of hydrogen is cheaper than transmitting the same amount of energy as electricity. However, hydrogen produced by low-cost renewables may not occur when it is needed the most (i.e. during periods of peak energy consumption), and therefore intermittent or even seasonal grid-scale storage is required. Dr. Allison discussed how hydrogen may be phased in by blending it into the existing natural gas pipeline system, but this will require the installation of additional compressor capacity doing more work at pipeline stations to maintain the same energy flow in the pipeline due to the properties of hydrogen and its effect on compression. It is also important to ensure the compatibility of materials and uses (e.g. gas appliances) with hydrogen. Limited hydrogen pipelines already operate in both Europe and the U.S. (typically associated with the petrochemical industry), with bulk hydrogen being stored in salt dome caverns. Dr. Allison described the thermodynamics of hydrogen compression while discussing the differences between the reciprocating and centrifugal types of compressors most commonly used for hydrogen compression. He also pointed out other important design considerations for pipeline infrastructure due to hydrogen's properties, such as the effect on vortex shedding, pulsation control, and cooling.