FUTURE ENERGY EXPORTS

Cooperative Research Centre

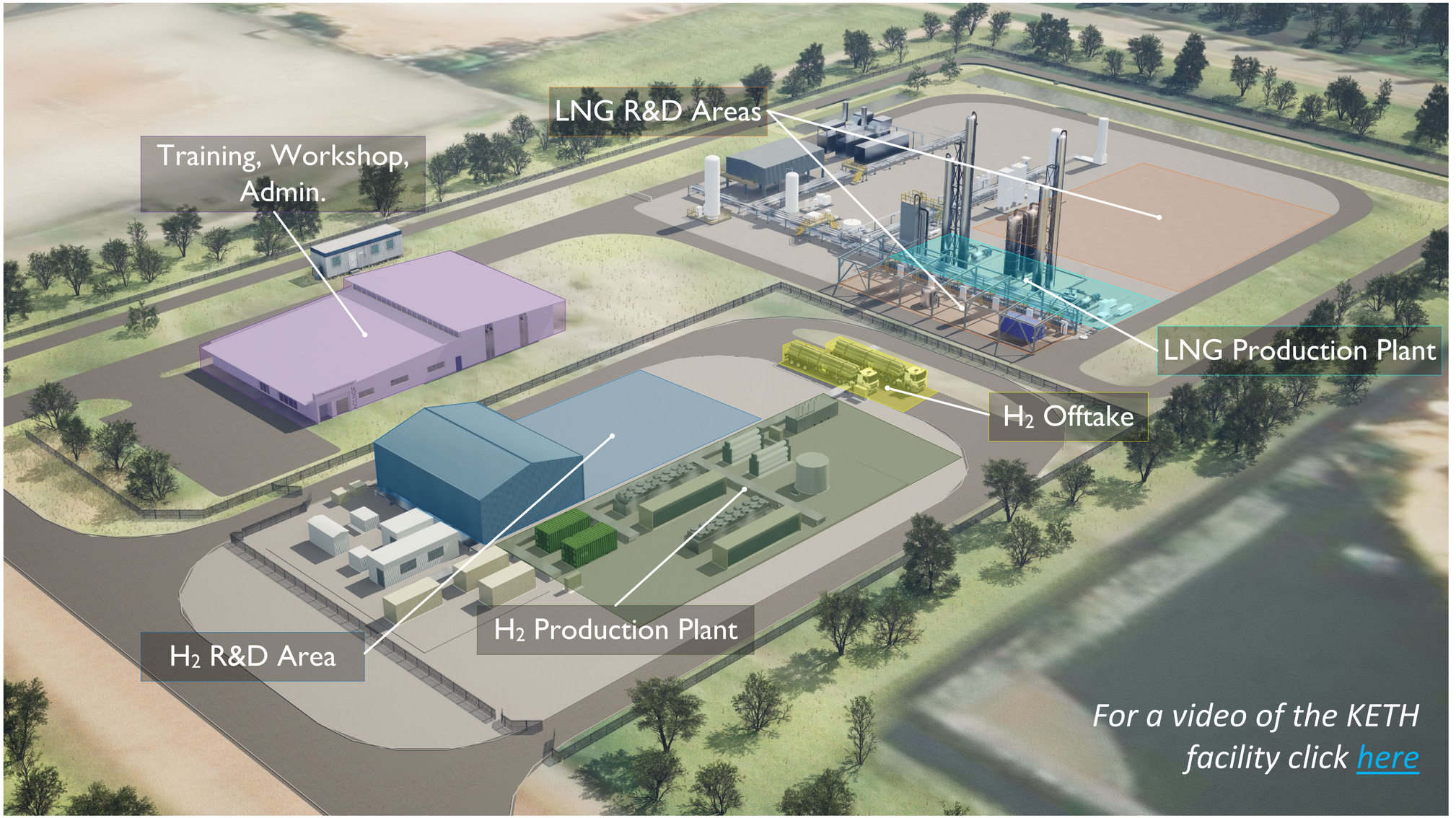
KETH Kwinana Energy Transformation Hub

Overview of Use Cases for the Kwinana Energy Transformation Hub:

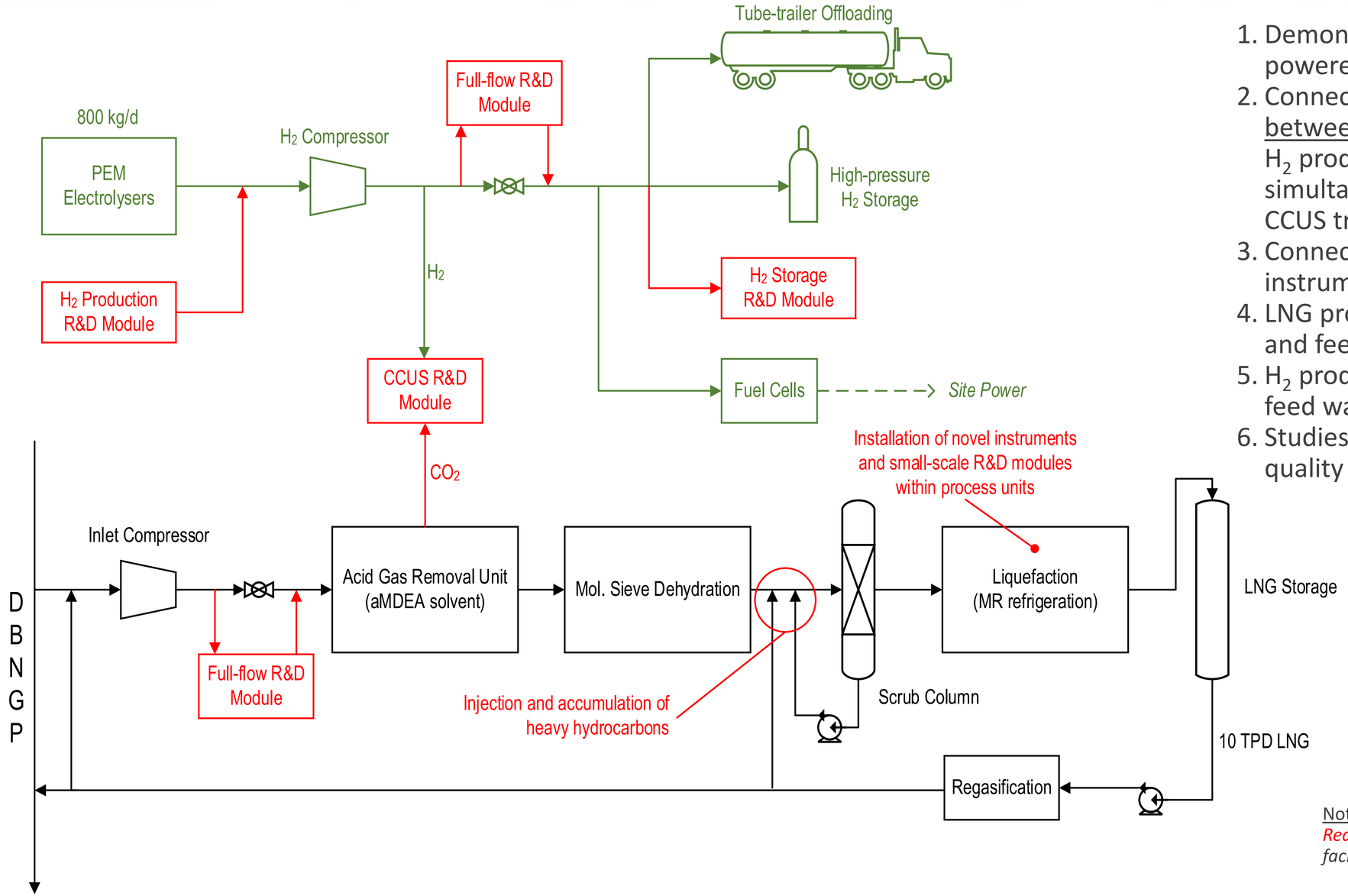
LNG, H_2 and CO_2 Technologies

[Technical Version]

Main Areas of the KETH Facility



How KETH Supports R&D



1. Demonstration of a fully electrified LNG plant, powered by renewable energy and hydrogen fuel cell.
2. Connection of full-scale modules at tie-in points between process units. This includes tie-in of full-scale H_2 production and storage modules, as well as simultaneous connection to LNG and H_2 plants for CCUS trials.
3. Connection of small-scale modules and instrumentation at tie-in points within process units.
4. LNG production trials with varying LNG train pressure and feed compositions
5. H_2 production trials with power cycling and varying feed water quality to study electrolyser performance
6. Studies of fuel cell performance with varying feed H_2 quality

Notes

Red R&D modules are not part of the base KETH facility.

Categories of R&D Use Cases

R&D use cases presented here have been identified by industry and academic stakeholders in KETH. They are grouped into the following categories:

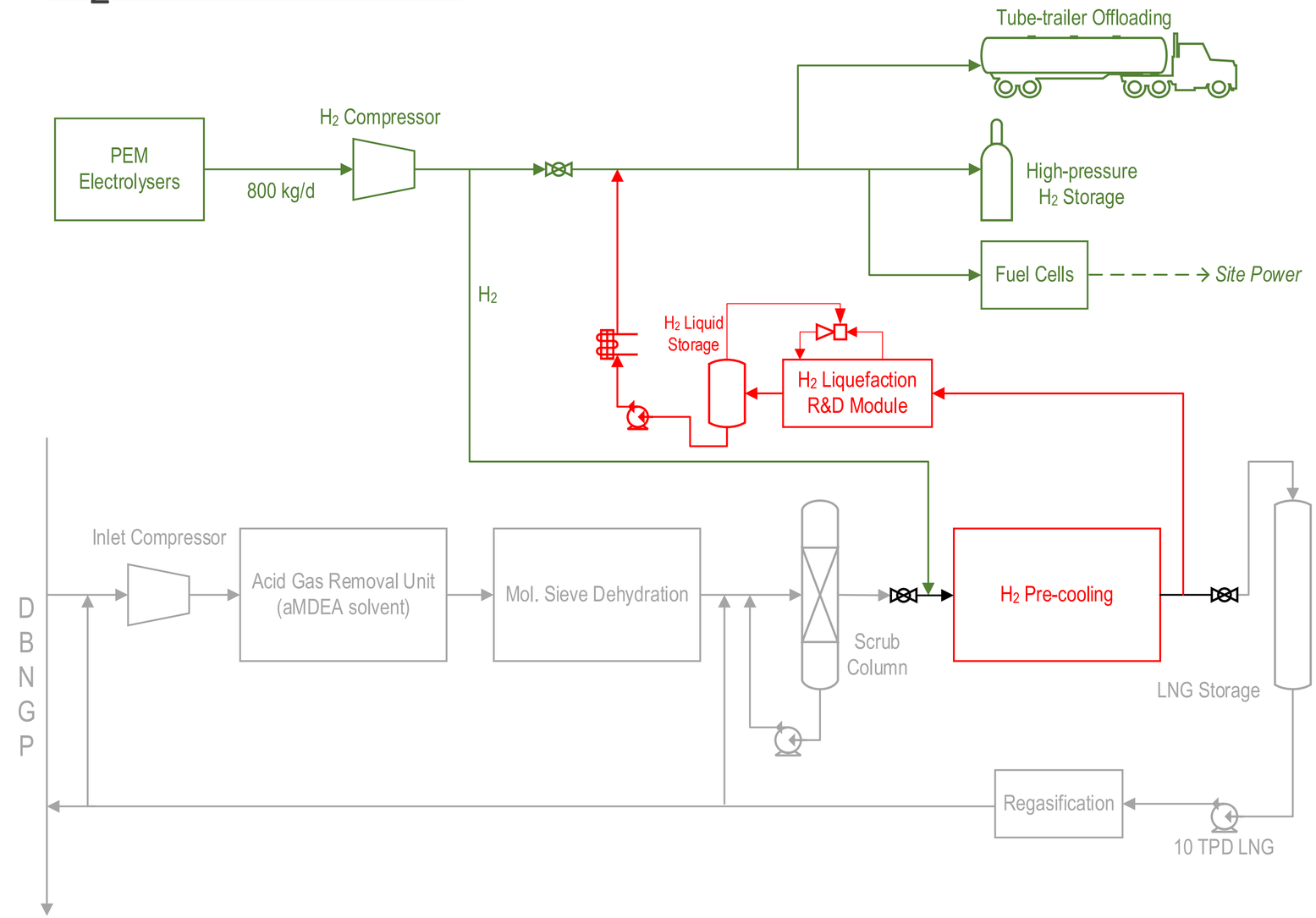
1. Next Generation Plant
2. Shutdown Prevention
3. New Value Streams
4. Operation Optimisation
5. Process Safety Testing
6. Data Analytics
7. Maintenance

Many of the use cases benefit from the ability to create R&D campaigns where the LNG and H_2 plants operate in non-optimal or unstable regions. KETH is designed with a wide operating envelope to permit disruptive tests.

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders

H_2 Liquefaction



KETH provides a stream of high-pressure H_2 at 800 kg/d for testing H_2 liquefaction and regasification process alternatives.

In the example shown here, the mixed refrigerant cycle within the LNG train is tested as H_2 pre-cooling, to determine whether LNG infrastructure can be repurposed for LH_2 production.

Regasified H_2 can be for sold via KETH H_2 gas offtake facilities.

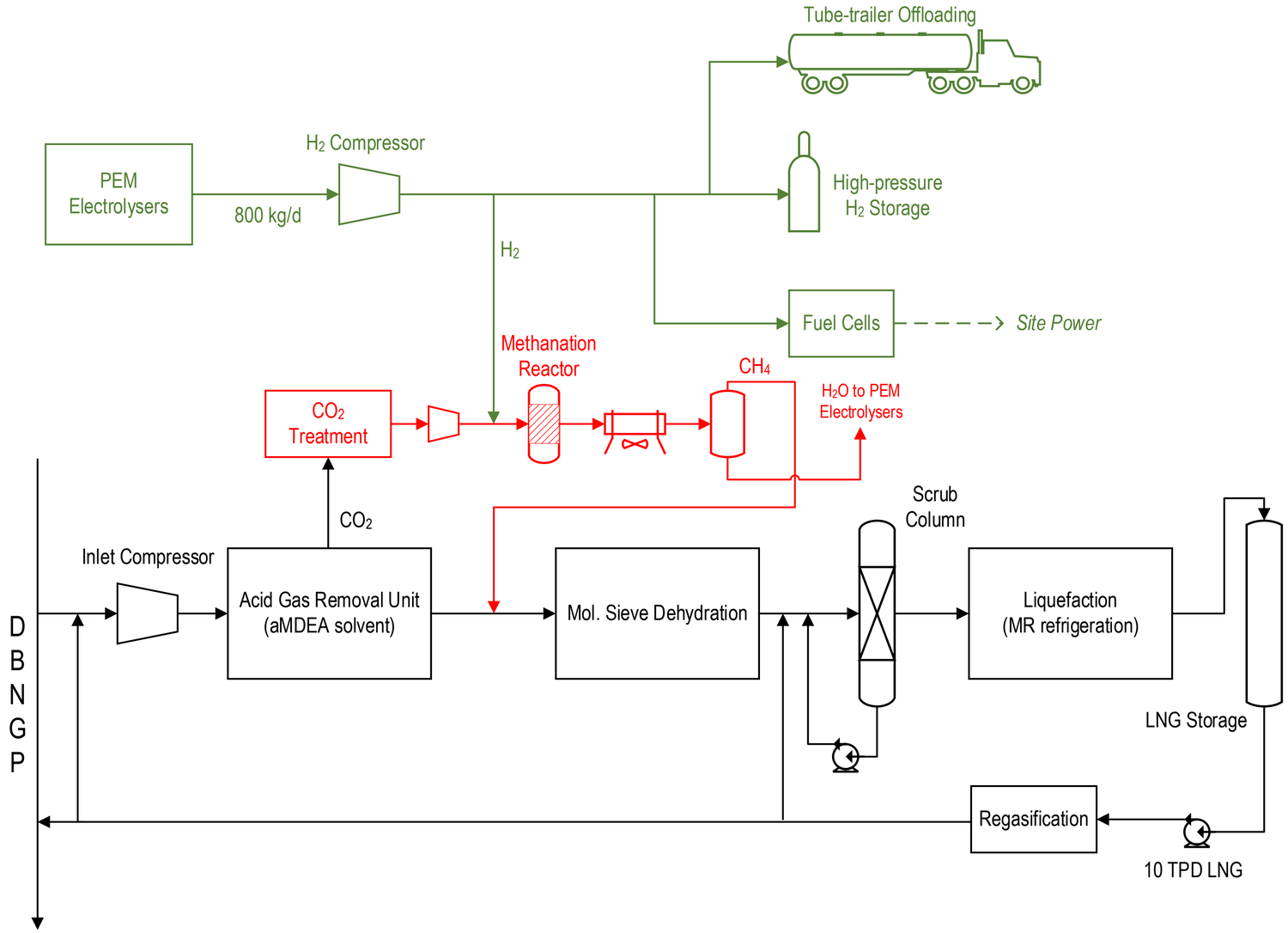
Benefits For Industry:

1. Identification of liquefaction technologies with low energy consumption and best operability
2. Refinement of process models with plant data, leading to better designs and plant simulations
3. Opportunity to witness units in operation before deployment in commercial plants
4. Qualification of liquefaction units in operating environment

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders

CO_2 Methanation



Methanation of CO_2 emitted from the LNG train AGRU can decarbonise LNG production by reducing plant scope 1 emissions, and is an alternative to CO_2 sequestration.

AGRU vent and H_2 streams are combined in a reactor in the KETH R&D area, producing methane and water. The methane is routed to the KETH LNG train and processed to make additional LNG.

KETH enables long-term testing to troubleshoot the integration of methanation with LNG train operation.

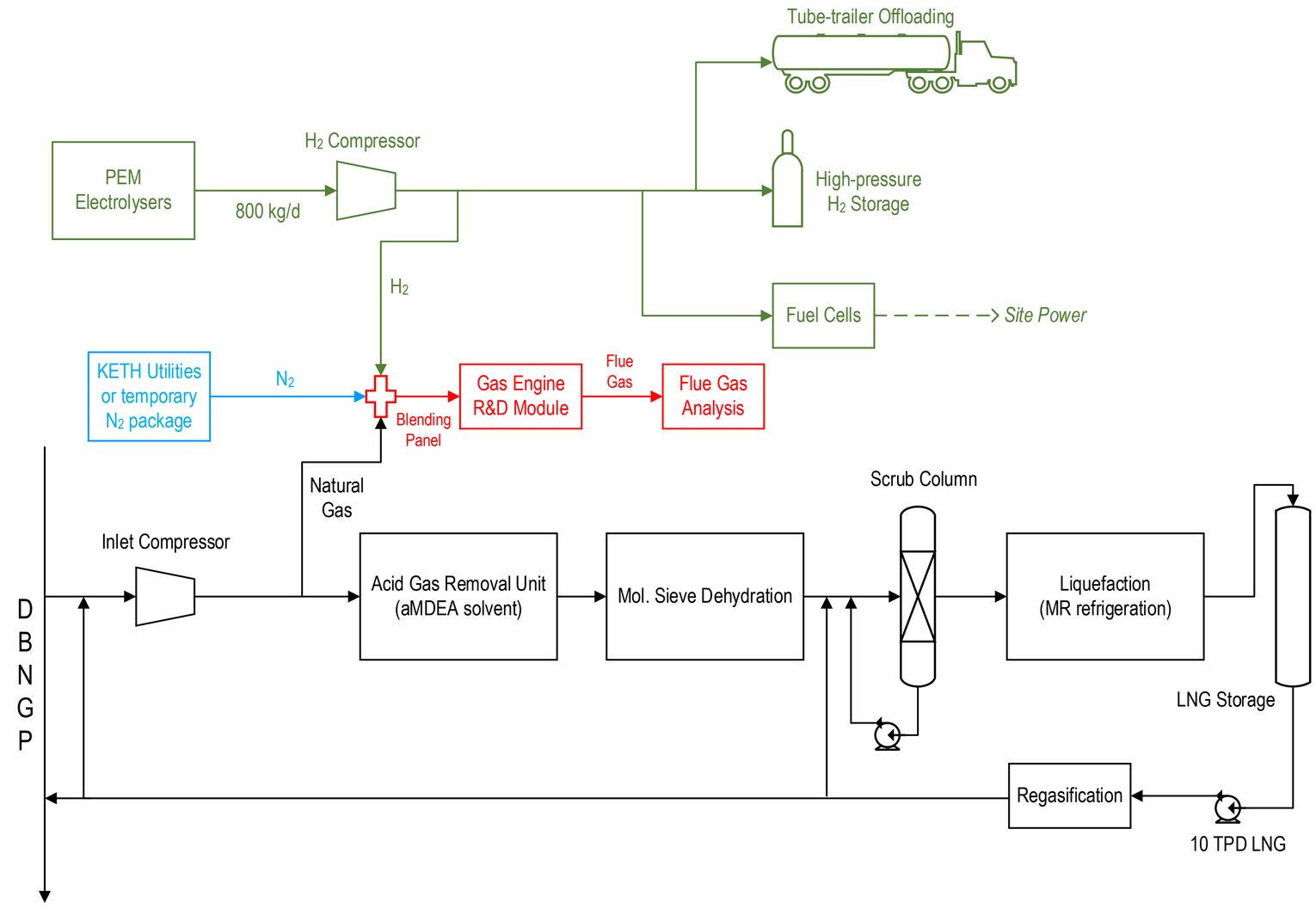
Benefits For Industry:

1. Identification of commercially sustainable methanation technologies to reduce scope 1 CO_2 emissions and increase methane (LNG) product.
2. Understanding operability issues caused by integrating methanation with LNG production.
3. Refinement of procedures and operator craft around methanation through long-term trials at KETH.

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders

Reduction Of Combustion Emissions



Continuous natural gas and H_2 streams are blended with N_2 from KETH utilities, or a separate N_2 package. This blend is fed to a gas engine (e.g. turbine) in the KETH R&D area. The module would be fitted with analysers for flame temperature, flue gas composition, and other relevant process variables for data analysis.

Other options within this use case include alternative H_2 sources, such as autothermal reforming (ATR), which would be coupled with an air separation unit to supply O_2 to ATR, and N_2 to the gas engine.

Benefits For Industry:

1. Understanding benefits and issues that arise when blending H_2 into fuel used for gas engines
2. Obtaining real plant data from trials at KETH to support commercial decisions to switch to blended fuels
3. Identification of optimal blends for different engine types

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders

Snapshots taken from KETH marketing animation, available from: keth.com.au or youtube.com/watch?v=vcHvNmm33CY

Operator & Engineer Training Programs

KETH will be the only live H_2 and LNG training facility in the southern hemisphere. Areas of training include:

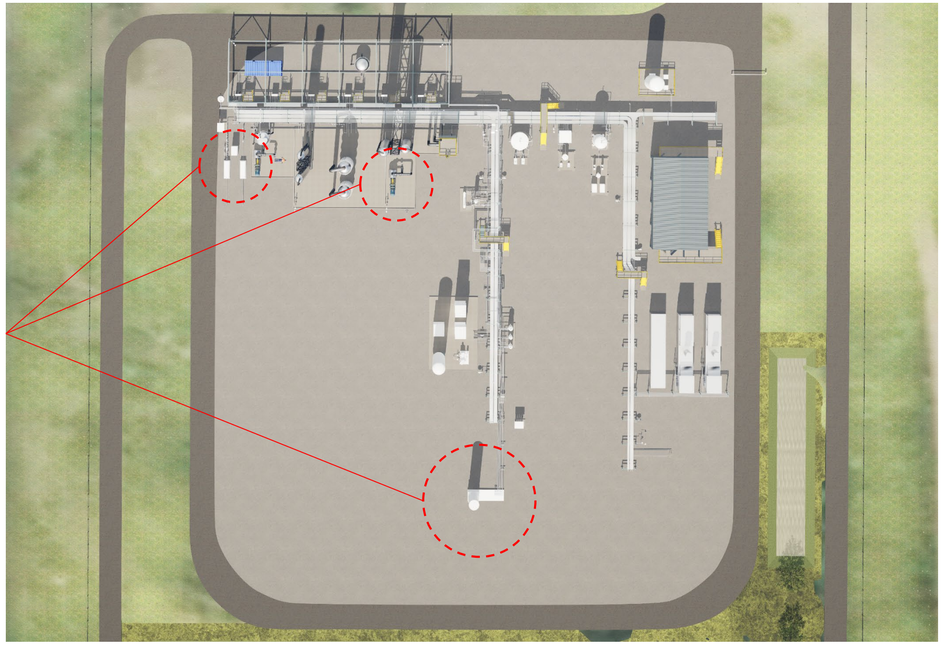
- General LNG training for operators, technicians, and maintainers
- H_2 fundamentals and H_2 plant safety
- Maintenance and shutdown training
- Undergraduate training, including process safety
- Bespoke training for individual organisations
- Subscription service for use of KETH Digital Twin
- Self-directed remote learning

Benefits For Industry:

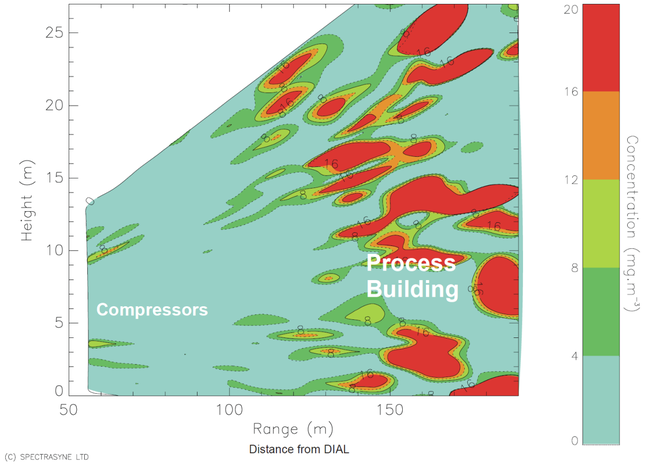
Trainee operators obtain real LNG and H_2 plant experience before starting work, leading to fewer incidents and better operator craft in industry.

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders



KETH enclosed ground flare (warm-wet, cold-dry, and sour burners) and rotating equipment (inlet compressor, MR compressor) provide fugitive emission sources for testing measurement technologies and new low emissions modifications.



Bottom two images from "DIAL Measurements of Fugitive Emissions from Natural Gas Plants and the Comparison with Emission Factor Estimates" (Chambers et. al; 2006)

Fugitive Emissions

KETH enables fugitive emissions R&D in the following areas:

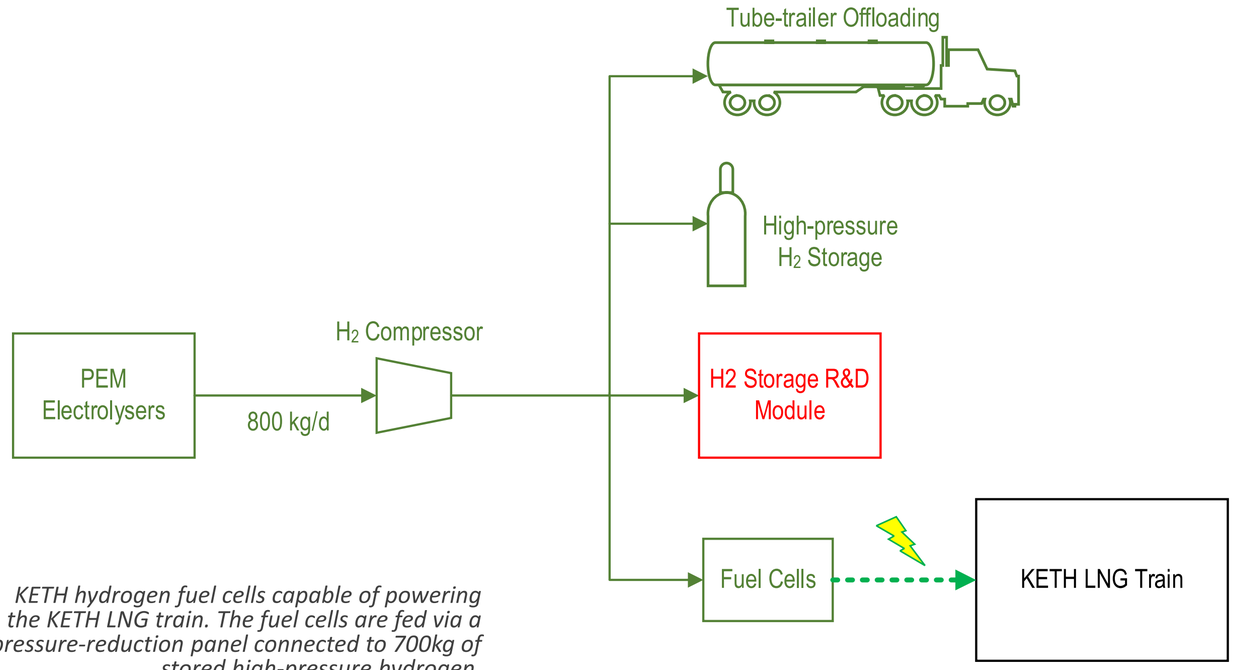
- Methods to reduce the methane measurement gap, caused by differences between top-down measurement methods (LIDAR, drone-mounted sensors) and bottom-up emissions factor methods.
- New technologies to detect and monitor natural gas plant 'bad actors', and low cost modifications to restrict emissions from these equipment items.
- Process designs for aggregating and upgrading dilute methane to pipeline specification.

Benefits For Industry:

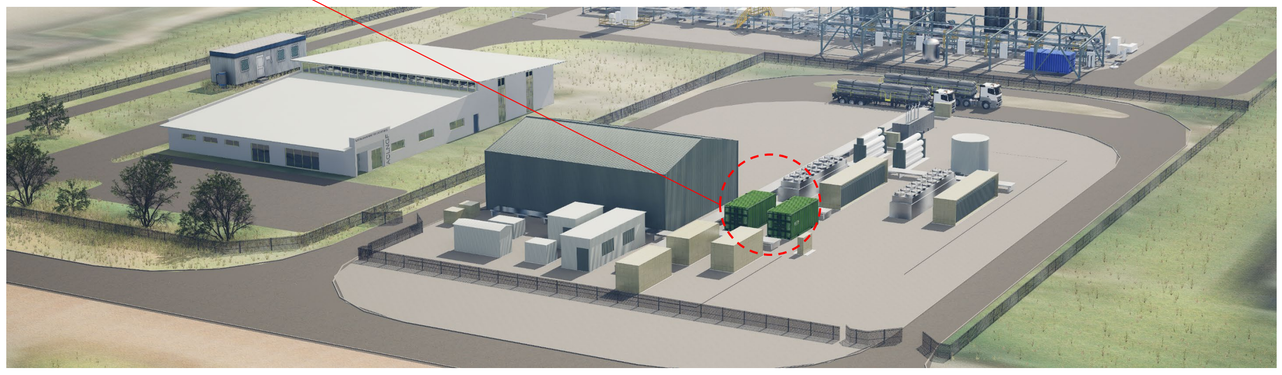
1. Qualification of new, low cost methods to estimate fugitive emissions and meet reporting requirements
2. Identification of valuable plant modifications to substantially reduce fugitive emissions

Highlighted Use Cases

Use cases of particularly high value or broad appeal across stakeholders



KETH hydrogen fuel cells capable of powering the KETH LNG train. The fuel cells are fed via a pressure-reduction panel connected to 700kg of stored high-pressure hydrogen.



H_2 Battery for the Process Industries

The KETH H_2 plant includes 700 kg H_2 storage and fuel cells that produce electrical power sufficient to power the LNG train.

A solar PV system on the main building rooftop generates a renewable power profile. This profile permits the PEM electrolysers to generate H_2 as if coupled to a renewable power supply.

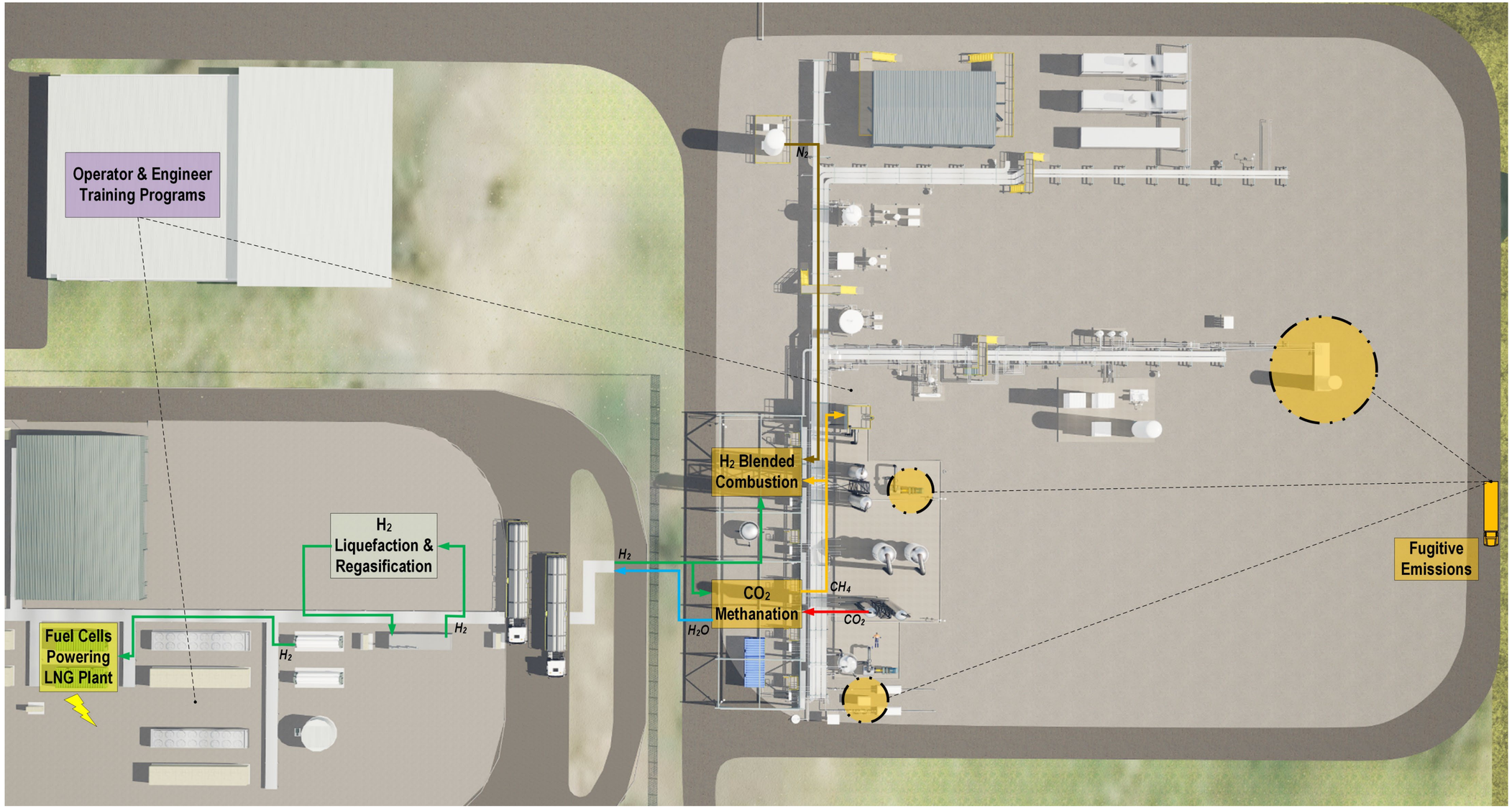
KETH can run test cases for powering process equipment using gaseous H_2 storage and fuel cells as a 'battery' for process plant. This configuration overcomes footprint limitations of typical batteries such as lithium-ion.

New gaseous H_2 storage technologies, such as metal hydrides, can be tested in combination with the KETH fuel cells.

Benefits For Industry:

1. Integration of KETH H_2 production with LNG train power will enable industry to identify optimal production, storage, and consumption capacities, and associated process control strategies, for commercial deployment.
2. Identification of best H_2 storage technologies to use as a 'battery'.

Highlighted Use Cases at a Glance



Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022

NEXT GENERATION PLANT: use cases that involve substantial modules being tied into the KETH LNG and H_2 plants.

1. N_2 adsorption unit upstream of the installed LNG Liquefaction unit. Upstream N_2 removal removes the current energy inefficiency of liquefying the N_2 in the natural gas and then flashing it out of the LNG product.

2. Utilising LNG Liquefaction to pre-cool H_2. This activity would be completed as part of a larger H_2 liquefaction project (*Use Case 1* slide), and would investigate the extent to which existing LNG infrastructure can be repurposed for H_2 cooling and liquefaction.

3. New LNG regasification units. These technologies would aim to use the 'cold energy' of LNG; for example, to generate electricity, or to cryogenically separate impurities such as CO_2 from pipeline gas.

4. More compact versions of typical process units for deployment offshore or, generally, in enclosed areas. One such example is membranes for offshore bulk CO_2 removal. The KETH LNG train units can be bypassed, so that new units can take the full-flow of the LNG train and operate continuously as part of the KETH LNG train.

5. Novel cryogenic gas processing technologies, including: membrane separation at cryogenic conditions to remove N_2 from scrub column overheads; testing of tube geometries and configurations for cryogenic heat transfer.

6. LNG storage and utilisation technologies, including new insulation to reduce boil-off, and LNG fuelling systems for the marine industry. In the case of LNG tank insulation R&D, the insulation material for the KETH LNG storage tank could be modified, or a test storage tank brought on site and tied into the LNG rundown line.

7. CO_2 utilisation technologies for the AGRU vent, such as aqueous mineralisation processes. The KETH AGRU generates an acid gas mixture rather than pure CO_2, providing a realistic feedstock for qualifying CO_2 utilisation technologies for the gas industry.

Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022.

NEXT GENERATION PLANT (CONT'D): use cases that involve substantial modules being tied into the KETH LNG and H_2 plants.

8. Refrigeration cycles for H_2 liquefaction. *See Use Case 1 slide.*

9. Demonstrating new commercial technologies for the emerging H_2 industry. With large-scale use of H_2 energy still an emerging industry, there are no settled or 'industry standard' technological solutions. Various vendor offerings spanning production, processing, storage, and end-use will be trialled at KETH. The installed H_2 plant at KETH provides baseline operating data against which alternative technologies can be compared. Within the KETH H_2 plant, new instrumentation, such as flow meters and leak detectors, will be installed and tested.

10. H_2 fuel cells for powering process plant. *See Use Case 6 slide.*

11. Demonstrating the H_2 value chain. KETH will sell green H_2 to third parties for various uses. Technical and commercial arrangements for product storage, transport and transfer will be evaluated and the total value chain optimised.

Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022

SHUTDOWN PREVENTION: use cases that involve sensor testing and data acquisition during unstable modes of operation. Because of its R&D focus, KETH can be operated in modes where there is a high risk of trip to prove the functionality of a technology.

1. Hydrocarbon freeze-out sensor, installed on gas feed to LNG plant liquefaction unit. UWA has developed an online sensor that accurately measures freeze-out temperature by sampling and rapidly freezing a small quantity of gas. The sensor would avoid composition thresholds (e.g. C5+, BTEX) for liquefaction, and instead report a temperature threshold. The sensor would enable scrub column debottlenecking as well as mitigate shutdowns caused by freeze-out events.

2. Accurate freeze-out models, that predict formation and growth of solids in cryogenic heat exchangers. The KETH LNG plant can be dosed with heavy hydrocarbons to form solids, generating process data for building and verifying freeze-out models.

3. AGRU foaming prevention. The ability to vary the feed composition of the KETH LNG plant permits AGRU performance to be investigated under a range of conditions. This capability is particularly relevant to commercial plants with changing feed composition over the plant's lifetime. KETH will enable the testing of new sensors to detect early onset of foaming, anti-foam optimisation, as well as technologies such as upstream water wash that prevent foaming.

Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022

NEW VALUE STREAMS: use cases that involve substantial modules being tied into the KETH LNG and H_2 plants to test recovery and production of additional products.

1. Non-cryogenic helium recovery processes. Helium is a high-value natural resource present in low concentrations in Australia's gas fields, and has been recovered through the Darwin LNG plant's nitrogen rejection unit (NRU). This activity would test alternatives to the NRU for recovering helium from natural gas, such as dual-reflux pressure swing adsorption technology. For this activity, helium would be dosed into the KETH LNG plant and the dual-reflux PSA unit tied in at an appropriate location.

2. Methanation of CO_2 from the AGRU. *See Use Case 2 slide.*

Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022

OPERATION OPTIMISATION: use cases that involve study of KETH plant performance under various operating conditions. Some use cases also test new process control methods, instrumentation, and modifications that aim to improve plant performance.

1. LNG train trials close to the critical point. The LNG train inlet compressor permits operation at the critical point. The scrub column's high level of instrumentation will improve understanding of its operation at high pressures, enabling development of accurate models. Higher pressure operation lowers energy use but can give poor separation in the scrub column.

2. LNG train performance under changing feed conditions. The KETH LNG train can be injected with additional fluid components, and operated under various recycle modes, to alter composition. Examples include injecting CO_2, mercaptans, N_2, and heavy hydrocarbons. Trials would study impacts to train performance and find new optimal operating points.

3. Improving dryer bed regeneration. This activity would install a piping and compressor modification around the KETH LNG dehydration unit to quickly regenerate the driers without using a slipstream of dry gas, increasing forward flow to liquefaction.

4. Testing new materials, including anti-fouling coatings and other heat transfer materials used at cryogenic conditions.

5. Air-cooler performance characterisation, including in-depth studies of hot air recirculation and mitigations for this effect.

6. New LNG train control strategies, including 'self-tuning' APC, and automated LNG restarts that minimise flaring and venting.

7. New measurement and sampling systems for LNG trains, including flow measurement of cryogenic fluids, and advanced gas chromatography at the LNG train inlet.

8. H_2 blending to minimise natural gas combustion emissions. *See Use Case 3 slide*.

9. Investigating ways improve measurement, mitigation, and reporting of fugitive emissions. *See Use Case 5 slide*.

Complete Use Case List

Use cases developed through engagement with industry and research institutions 2018-2022

PROCESS SAFETY TESTING: use cases that involve installation and testing of new safety devices and safety systems for LNG and H_2 processing.

1. Testing relief valves, rupture discs, buckling pins, and other devices at cryogenic conditions. Some LNG plants employ novel designs for overpressure protection, such as staging valves in combination with buckling pins. Performance of these designs can be uncertain, and KETH would provide a testbed for checking design performance before commercial installation.

2. Cryogenic piping study, involving blowdown of the cryogenic end of the KETH LNG train to study piping temperatures and test against different piping standards.

3. Testing cryogenic spill protection systems, by applying custom-fit protection to equipment and monitoring performance.

DATA ANALYTICS:

KETH provides a testbed for demonstration and validation of software sensors, digital twins, and other data-driven technologies that support LNG and H_2 operations. Particularly, vendor offerings that predict or diagnose failures and other issues can be tested. Operators can therefore evaluate new software before choosing to deploy it on their commercial plants.

MAINTENANCE:

KETH provides a testbed for demonstration and validation of new maintenance technologies, including non-intrusive inspection technologies, such as phased array ultrasonic testing, and online installation of insulation. When qualifying new inspection technologies, KETH could be shut down to carry out traditional intrusive inspections and compare results with non-intrusive methods.