Control and monitoring of cryogenic and gaseous hydrogen for use in aerospace fuel systems

Nathan Nims

A&D Digitalization Business Manager - NI

Ben Richardson

Commercial Director – Filton Systems Engineering

Ben Richardson

Founded FSE in 2012

Background:

- Physics BSc
- Aircraft Fuel System Specialist
- Electrostatic discharge and lightning protection

Currently:

- Commercial Director & Fuel System Specialist

Nathan Nims

Joined NI in 2015

Background:

- Physics PhD
- Control System Engineer
- Applications Engineering
- Account Manager

Currently:

- Business Manager for A&D
- UK Security Lead

NI Background

NI has been involved in the launch of Space Vehicles for many years. Fuelling rockets requires the control and monitoring of:

- Liquid Nitrogen & Liquid Helium – for purging air and pre-cooling
- Liquid Oxygen
- Liquid Methane
- NTO (Dinitrogen tetroxide) + Hydrazine
- RP-1 Kerosene
- **Liquid Hydrogen**

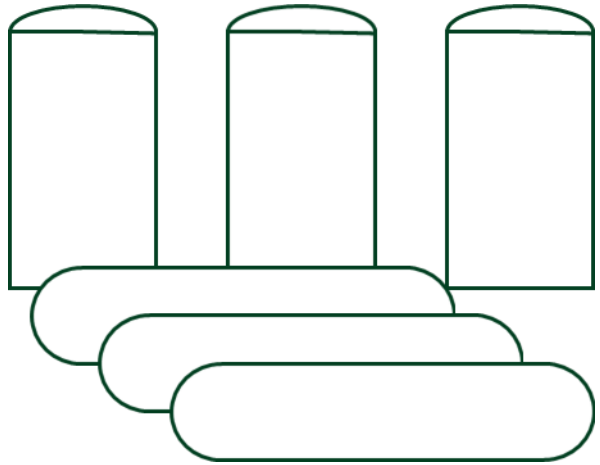
Launch Operations

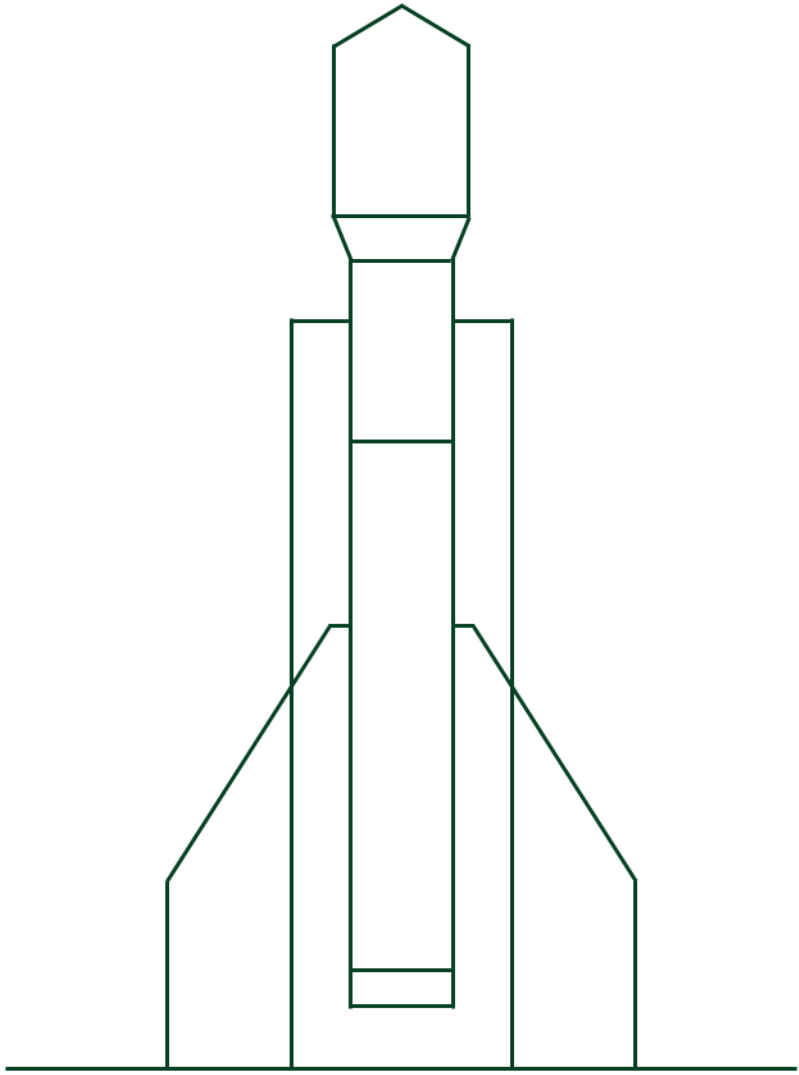
A successful launch of a space vehicle requires coordination across a complex array of functions.

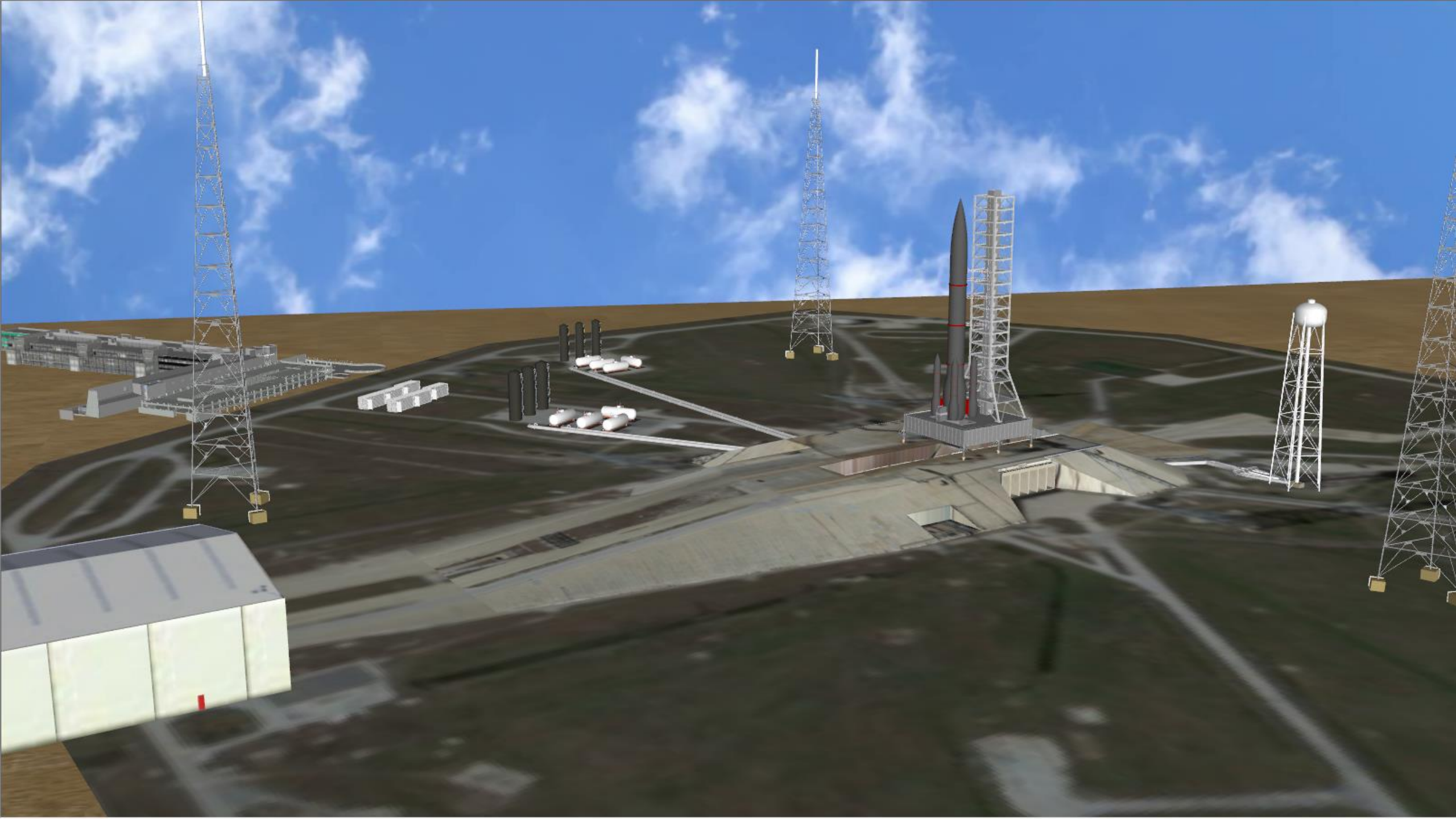
Launch operations systems prioritize:

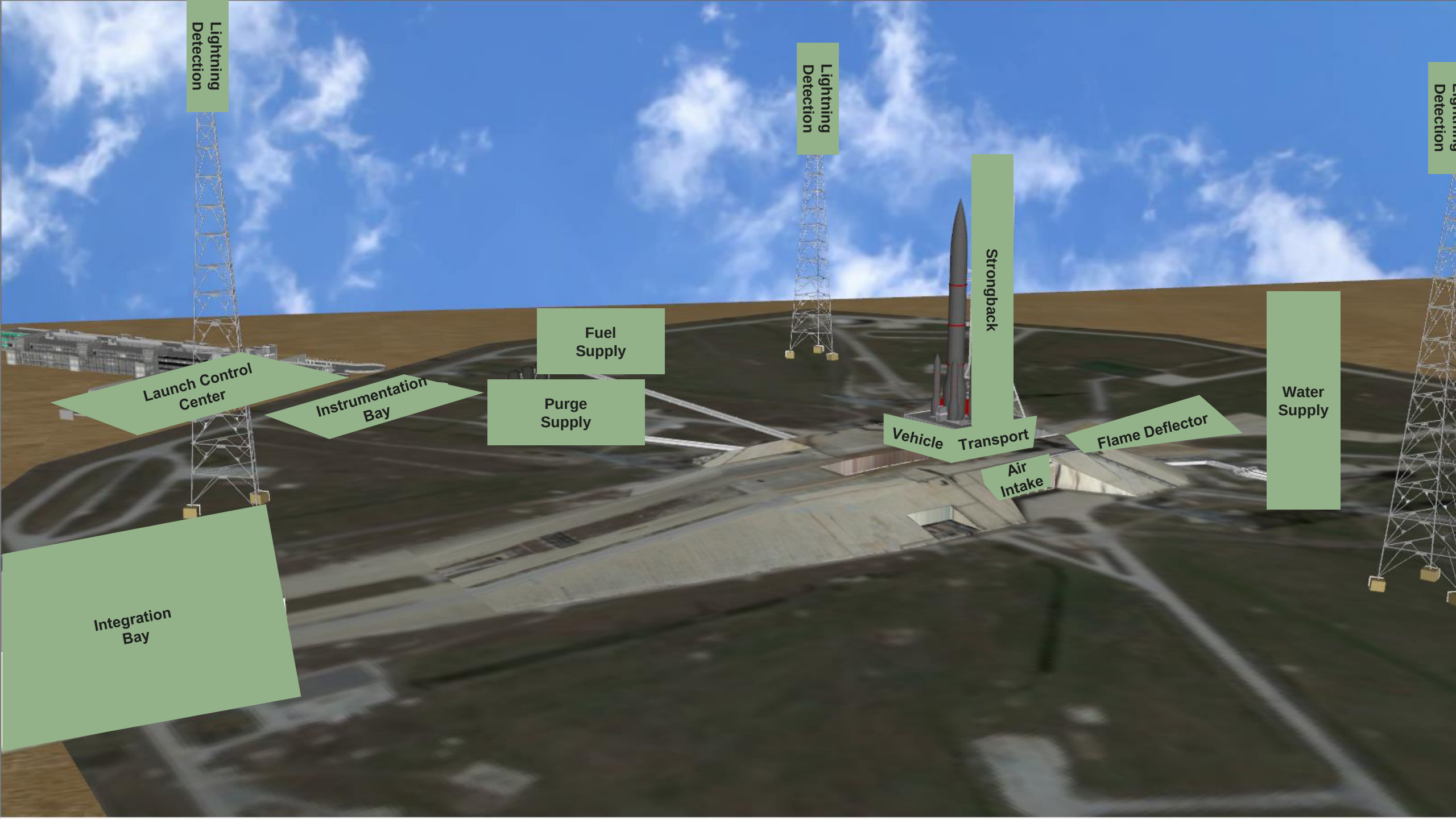
- Safety
- Reliability
- Accuracy

The **NI Launch Operations architecture** provides systems for monitoring and controlling launch operations systems.








Lightning Detection
Lightning Detection
Lightning Detection
Launch Control Center
Instrumentation Bay
Fuel Supply
Purge Supply
Strongback
Vehicle Transport
Air Intake
Flame Deflector
Water Supply
Integration Bay

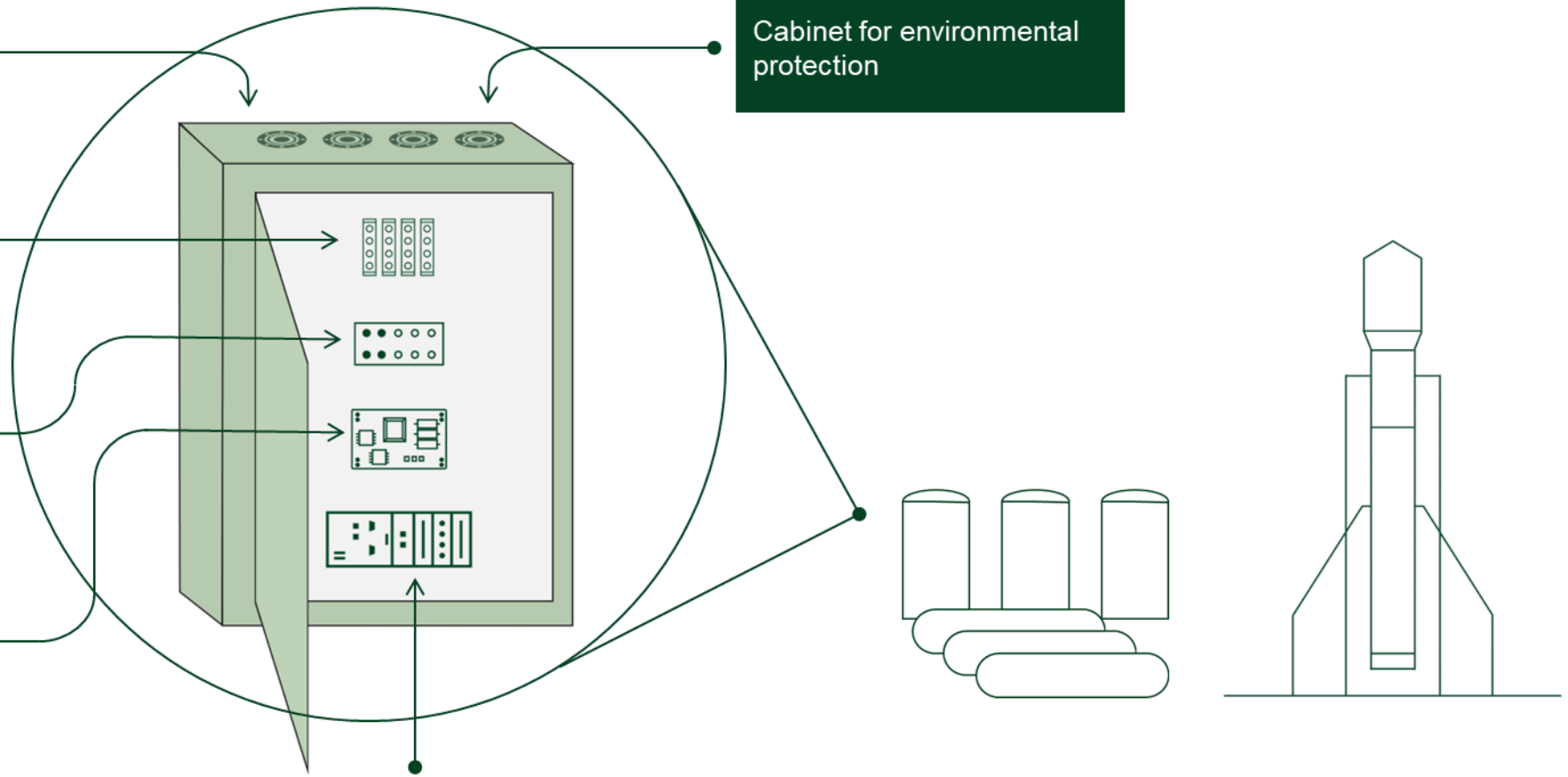
Launch Operations Control / Monitoring System

Connectors to run to launch facilities

Intrinsic barriers for environmental safety

Wire management for routing and debug access

Signal conditioning for isolation, filtering, excitation



Cabinet for environmental protection

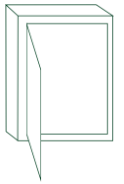
CompactDAQ for distributed acquisition/ CompactRIO for distributed control

Launch Operations Architecture

MIL Spec Circular Connectors | Commercial Connectors

Enclosure

Cable Management



Enclosure & Cabling

Isolation | Filter | Status Indicator | Solid State Relays | Intrinsic Barrier

Analog Voltage | Analog Current | Temperature (TC/RTD) | Vibration | Strain | Digital I/O | Relay | Frequency

C-Series Modules

Instrumentation

CompactRIO Controller | CompactDAQ Chassis

Control System

LabVIEW | C++ | Python

Development Software

Windows | Linux / Linux Real-Time

Application Software

Mission Control Software

Operation, Maintenance, and Regulatory Requirements

FSE Background

Engineering consultancy founded in Bristol 2012

Owned and operated by our engineers (Employee Ownership Trust)

Specialism in aircraft fluid systems, both compressible and non-compressible

Offers certification services, new product development, system & equipment qualification, modelling and test.

Offices in Bristol UK with test facilities in Gloucestershire and Cotswold International Airport.

60+ staff and steady year on year growth

Problem Statement

FSE has been working in both gaseous and liquid hydrogen since 2015 and gained significant expertise in the area.

Development focused on modelling and test rig design however progress was hampered by the lack of suitable facilities to validate models and perform verification testing.

FSE performed a review of test facilities suitable for early TRL testing with hydrogen fuel, no suitable venues were identified in the UK or Europe.

A feasibility study determined that the company's existing kerosene test site was well suited for an upgrade to a hydrogen handling facility. However no practical source of liquid hydrogen could be identified, bulk liquefaction is performed on the continent and as transportation becomes restrictive with the only viable source quoting minimum delivery quantities of 42,000 litres.

Technical Implementation

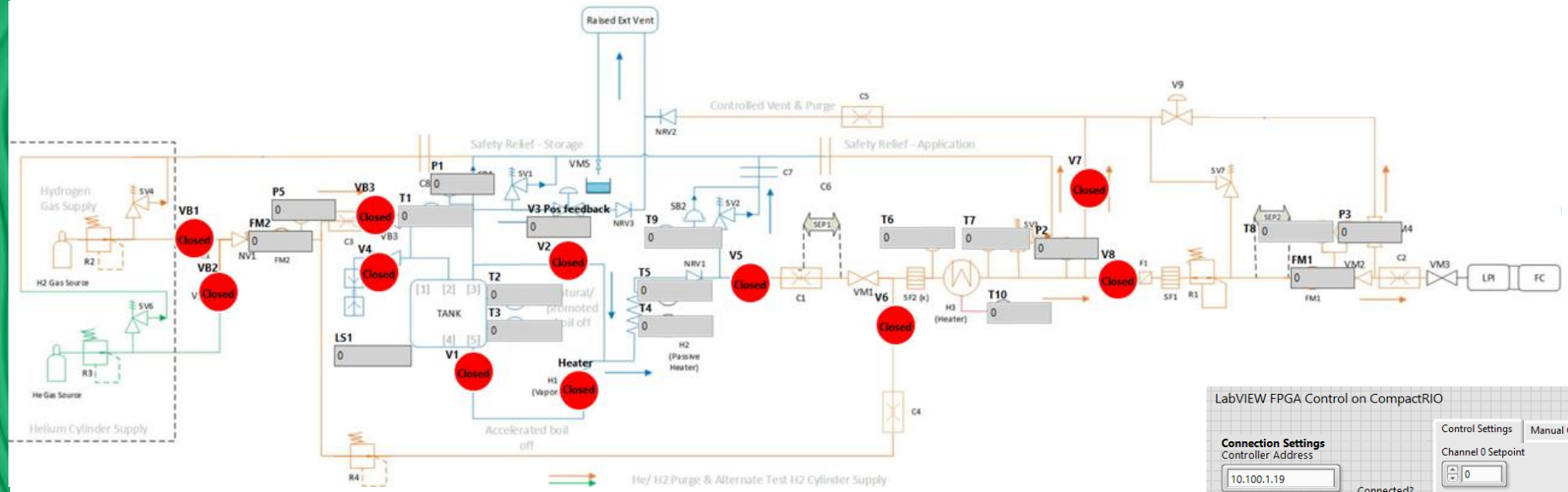
The test facility was modified to meet the British Compressed Gas (BCGA) Codes of Practice for the safe handling of flammable and cryogenic gases.

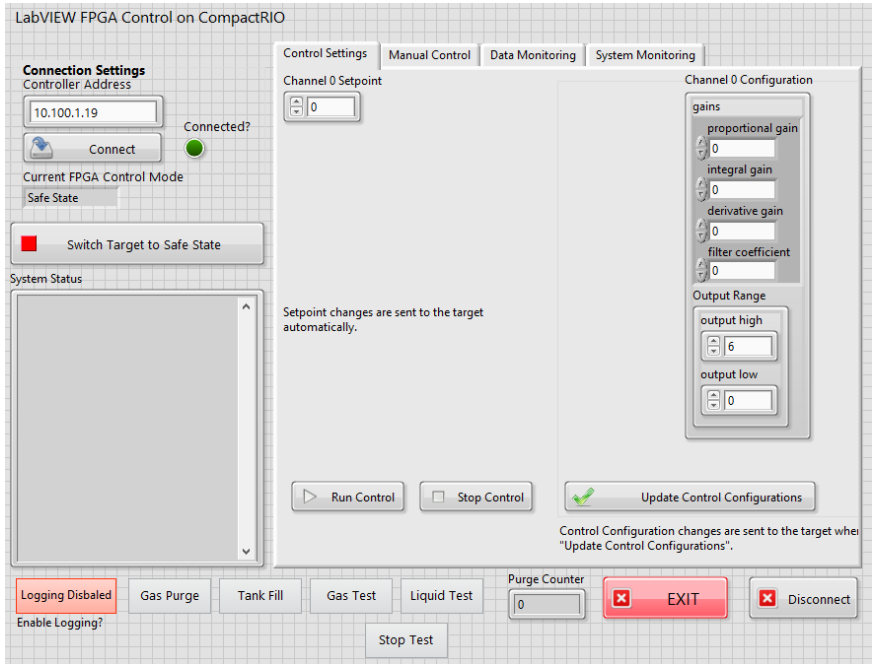
Keep out distances and ATEX zones were expanded while maintaining safe functionality of the kerosine rigs.

A liquefier was developed and built by FSE to enable the on-site generation of liquid hydrogen, the device currently accepts gaseous hydrogen from a bottled source but has been designed to be modular such that it can accept green and blue hydrogen in the future.

The liquefier system was commissioned in July and generated approximately 8kg of liquid hydrogen per day, currently we have onsite storage for 15kg (200L) of liquid hydrogen with plans to increase in the near future.

NI Software Implementation





- HMI driven through networked PC for user control and visualisation
- Embedded system with real-time operating system for deterministic closed loop control and monitoring
- Use of FPGA for the highest reliability and performance

NI Software Considerations

- Automation of sequences/tests or manual override
  - Each valve is individually addressable when running in ‘manual’ mode
- Real-time channel monitoring and alarming
- Data acquisition, scaling and logging for multiple sensors and data types:
  - Flow meters, level sensors, silicone diodes, RTDs, pressure transducers and valve position feedback
- Modular code approach – reusable, scalable and expandable
  - New functionality can be added with no/minimal changes to existing code
- Modular hardware approach allows for the addition of any standard interface:
  - 4-20mA sensors, RTDs, Thermocouples, CAN, Serial, Valve/Relay, Voltage input or output, Current output, Digital I/O

Challenges & Lessons Learnt

Technical challenges

- Low minimum ignition energy
- Small particle size, difficulty sealing
- Hydrogen embrittlement of commonly used materials
- Extreme cold temperature (13K at cold face, 23K to achieve liquefaction).
- Purging of system to avoid ignition threats and blockage (frozen air)
- Level sensing of generated hydrogen
- Detection of leaks and spillages

NI Lessons Learnt / Takeaways

- Requirements for high levels of reconfigurability, expansion to support ranging test campaigns
- Challenges in signal quality & current limits when using intrinsic barriers
- Need to develop manual/engineering + automated routines
- Connectivity – p2p vs cable loom solution.
- Need software that is easy to use (non-developer), but also onboard people to manage and evolve quickly.

Next Steps

- We’re in the process of upgrading to a 40 Kg per day system
- Onsite Hydrogen generation (reducing reliance on deliveries)
- Improving wiring management and connectivity scheme
- Prove out reliability of NI SW control system (currently 3 safety systems in place)
- Facility Upscaling at Cotswold Airfield with improved infrastructure
- Expansion of monitoring capabilities into material science e.g. stress/strain performance

Future Outlook

- Test facility offers flexible LH2 testing from early TRL to qualification. If you’re working in the H2 area, come and have a chat with us.
- NI have identified some key challenges we’re interested in addressing and would welcome input from potential users.