Summary of hydrogen plant implementation guidelines

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Agenda

1. Business Considerations
2. Technical Considerations
3. Nuclear Integration Concepts
4. Safety Considerations

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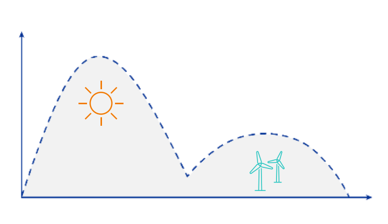
Business Considerations

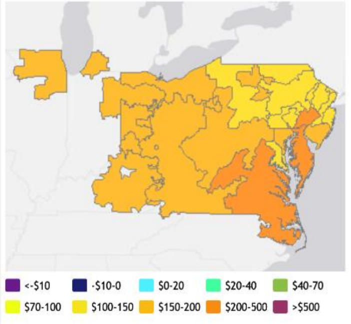
Business Considerations that are important for the design and technology selection

1



Operational Profile

2



Cost of Lost Generation

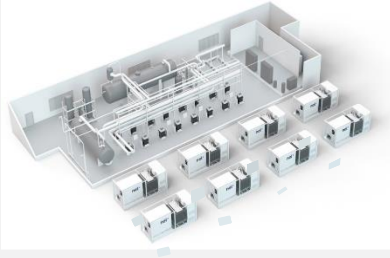
3

Off Takers

4

Hydrogen Revenue Potential

5



Capital Outlay

Every business arrangement will be unique and drive unique technical decisions

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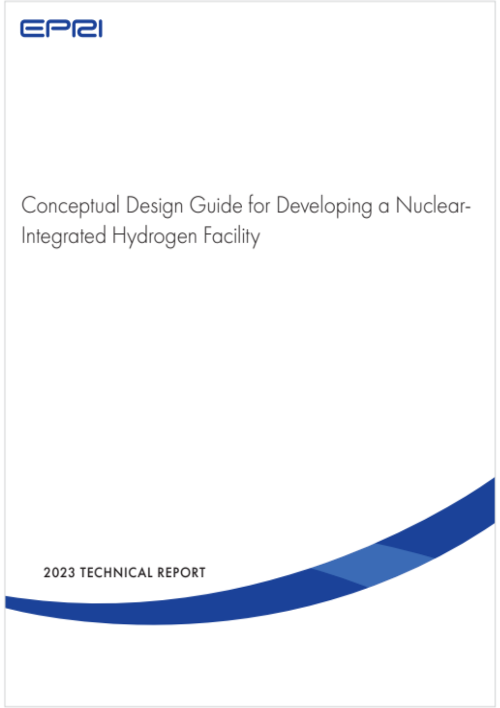
Technical Considerations

Nuclear hydrogen production

- Conceptual Design Guide for Developing a Nuclear-Integrated Hydrogen Facility (3002026514)


EPRI

Conceptual Design Guide for Developing a Nuclear-Integrated Hydrogen Facility

2023 TECHNICAL REPORT

- Methods of Nuclear Integrated Hydrogen Production (3002027703)
  - The following nuclear integrated hydrogen production methods are addressed:
    - Steam Methane Reforming
    - Autothermal Reforming
    - Biomass-Derived Liquid Reforming
    - Partial Oxidation
    - Coal & Biomass Gasification
    - Methane Pyrolysis
    - Chemical Looping Reforming
    - Thermochemical Water-Splitting (S-I and Cu-Cl)

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Technical Considerations for H2 production

General Planning

Technology Selection

PEM | Alkaline | HTSE

- Footprint and Configuration
- Stack / Component Degradation
- Startup and Shutdown
- Ramping Ability
- Design Parameters
- Performance Characteristics

Site Selection Considerations

Separation / Security Considerations

Operational Concepts

Hydrogen Plant Design

- Hydrogen Systems
- Cooling Systems
- Water Systems
- Building Requirements
- Utility Gas Systems
- Electrical Systems
- Structural Requirements

Nuclear Plant Integration

- Thermal Extraction
- Electrical Integration
- Cooling Water Integration
- Controls Integration
- Safety Evaluations

Project Planning

- Schedule Development
- Training
- Codes and Standards
- Maintenance
- Construction
- Licensing and Permitting
- Procurement
- Engineering and Design

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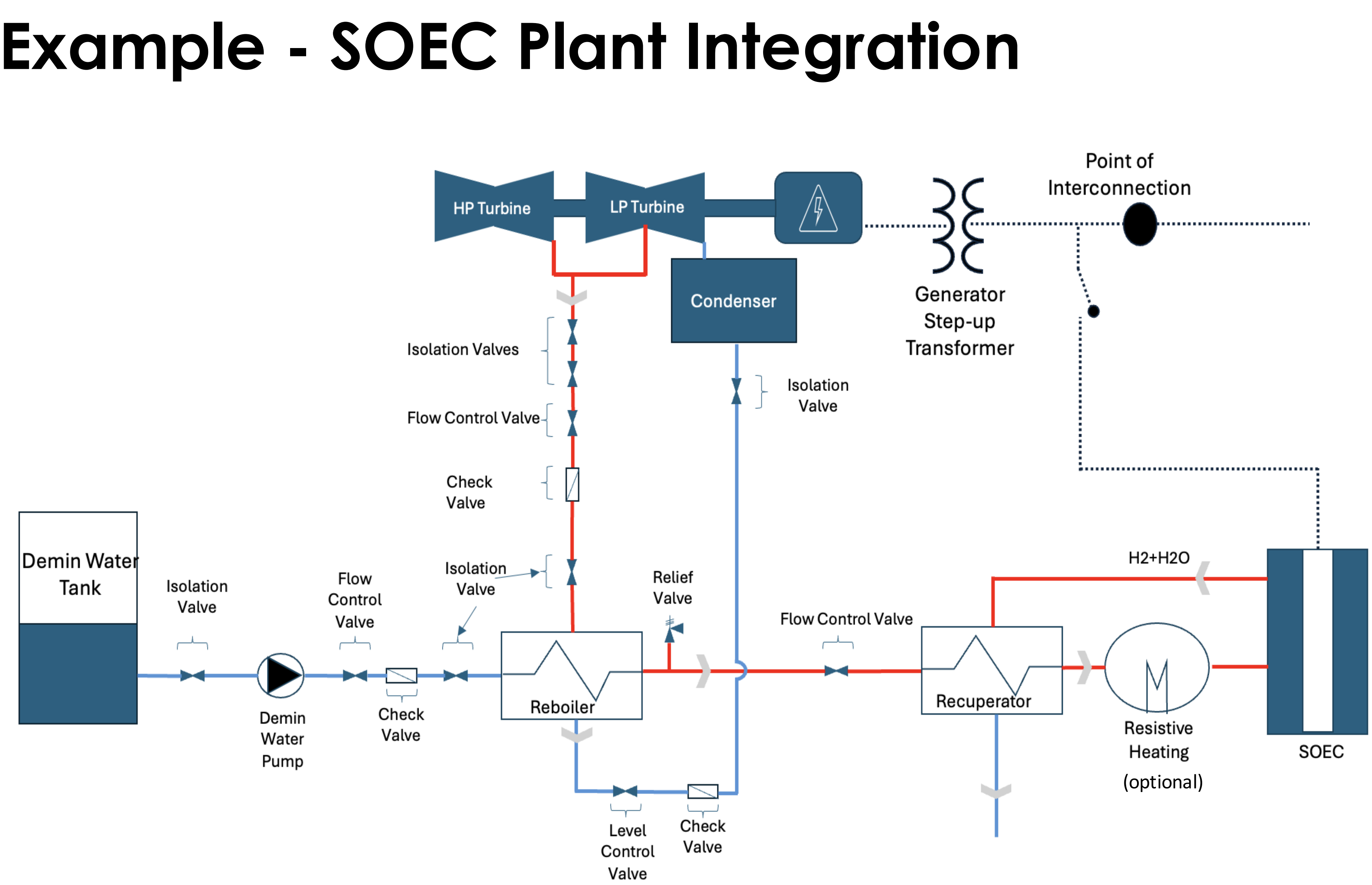
Example - SOEC Plant Integration



SOEC requires greater integration with the Nuclear Plant (electricity and heat) and closer physical separation

SOEC is most efficient with thermal and electrical integration.

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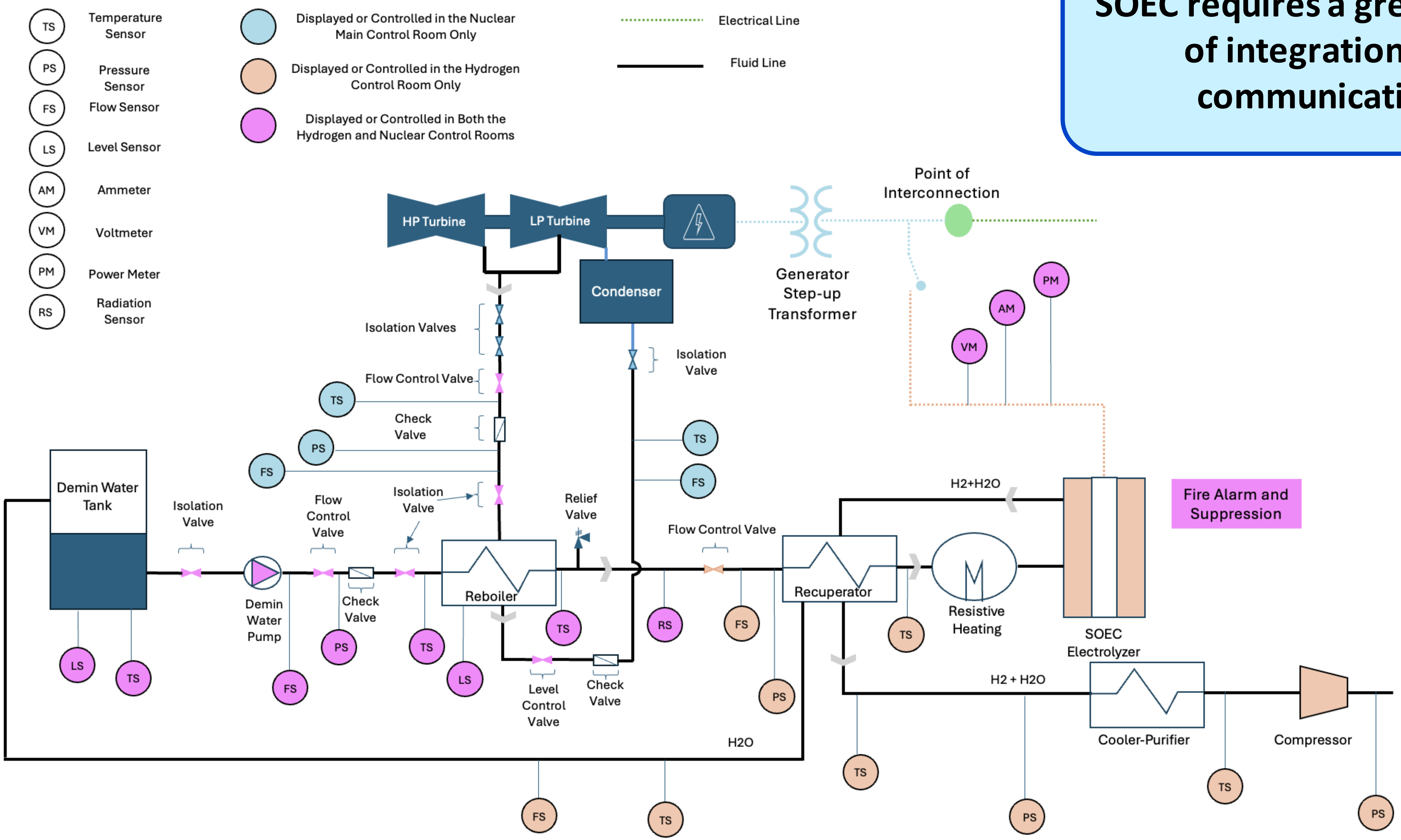
Example - SOEC Control Integration

SOEC requires a greater level of integration and communication.



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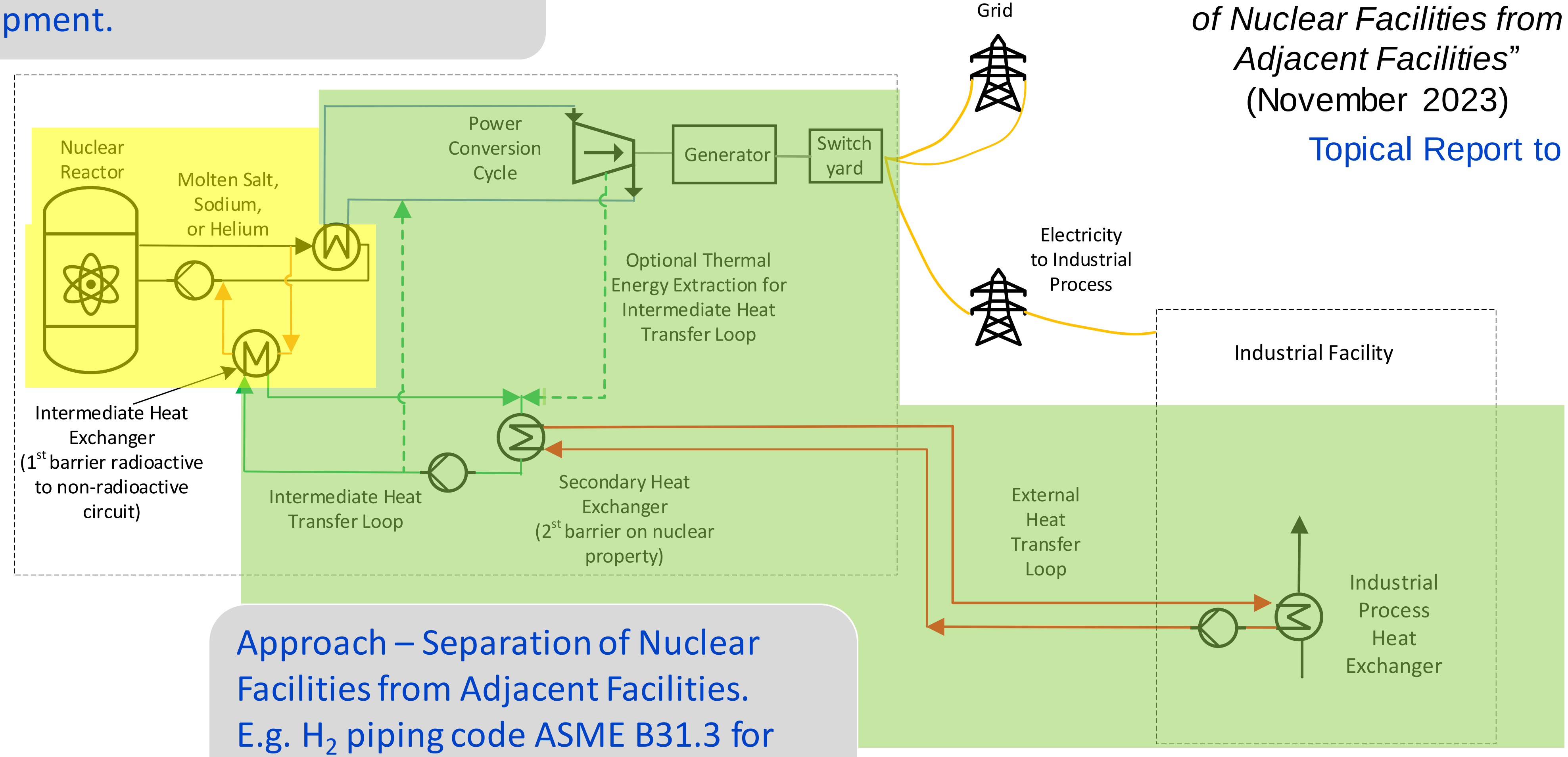
Approach: Separation Nuclear from Adjacent Facilities

Key approach – separation of nuclear safety related and non-safety related equipment.

EPRI Report 3002026499
"Technical Methodology to Demonstrate the Separation of Nuclear Facilities from Adjacent Facilities"
(November 2023)

Topical Report to US NRC submitted



Approach – Separation of Nuclear Facilities from Adjacent Facilities. E.g. H_2 piping code ASME B31.3 for Process Piping

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Safety Considerations

Safety Considerations – Accident Transients

- **Hydrogen Ignition Transients and physical Separation**
  - The Sandia National Laboratory created the software HyRAM+ (https://hyram.sandia.gov.) to assess the hydrogen and other alternative fuels (e.g. methane and propane) leak risk and ignition consequences.
  - Regulator Example: The U.S. NRC Regulatory Guide 1.91 Rev 3, "*Evaluations of Explosions Postulated to occur at Nearby Facilities and on Transportation Routes Near Nuclear Power Plants,*" provides an acceptable method for establishing a safe distance where overpressures from explosions should not exceed 6.9 kPa (1 psi) on plant structures.

On January 8, 2007, a hydrogen explosion at the Muskingum River Power Plant's 585-MW coal-fired supercritical Unit 5 (Ohio) caused one fatality, injuries to 10 other people, and significant damage to several buildings. The explosion occurred during a routine delivery of hydrogen when a hydrogen relief device failed, which allowed the contents of the hydrogen tank to escape and be ignited by an unknown source.

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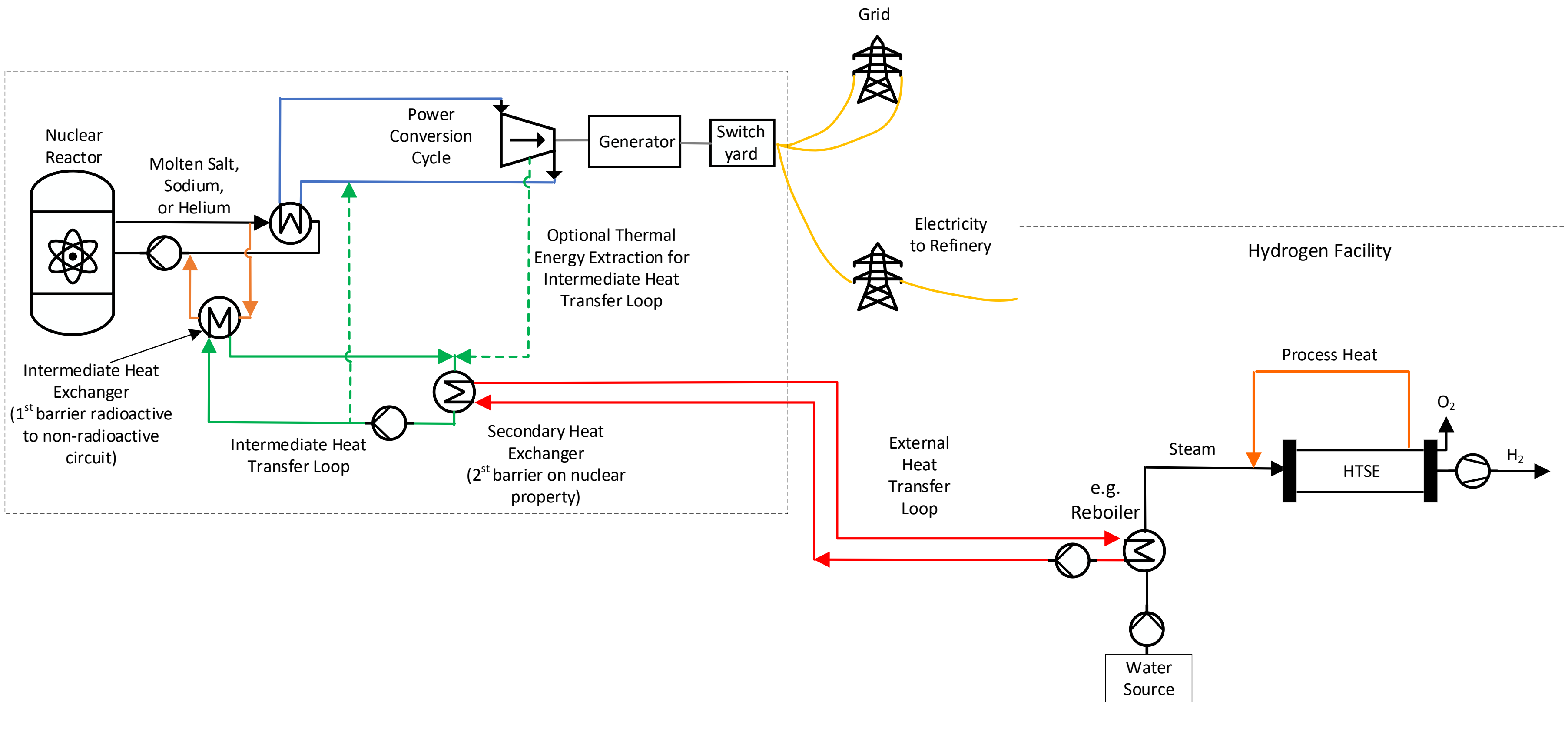
Safety Considerations – Accident Transients

- **Process Heat Transfer Transients (for heat integration, e.g. SOEC)**
  - A heat rejection from the hydrogen facility might impact the **power conversation cycle that can lead to a cascading effect.**



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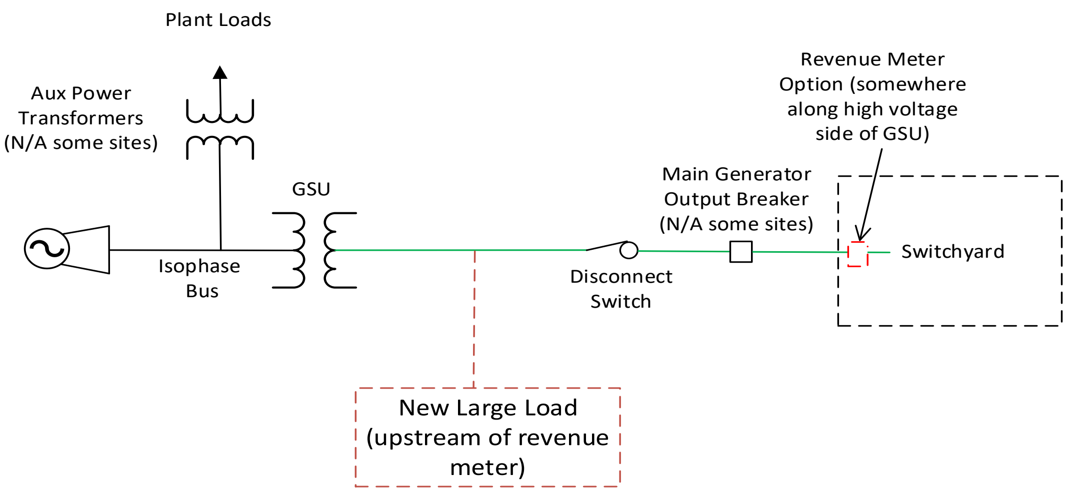
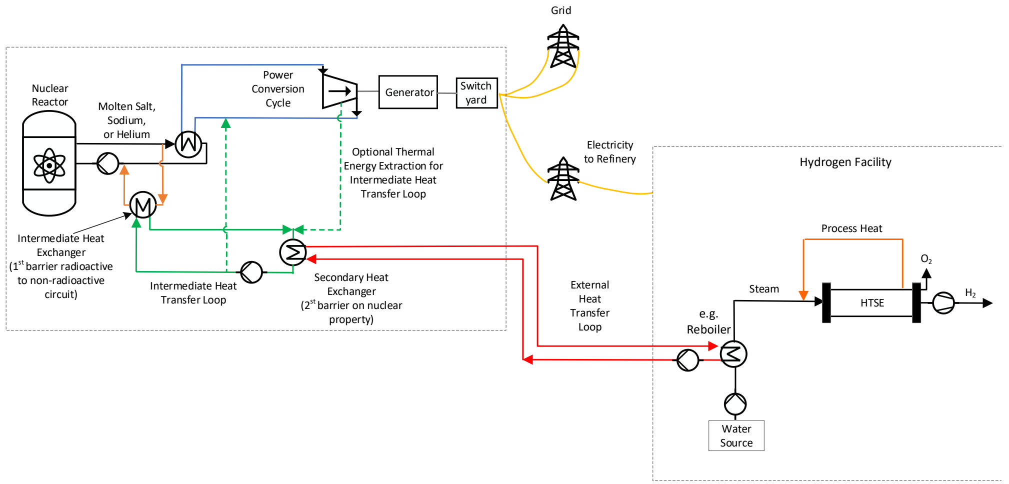
Safety Considerations – Accident Transients

- **Electrical Transients**
  - Load rejection from the hydrogen facility (e.g. electrolyzer stacks) when directly connected behind plant generator (behind the revenue meter).
  - A rejection of a large electrical load must be evaluated to assess the impact on the plant generator and other electrical transmission systems and components regarding stability, short circuit, load flow, harmonics, and protective devices.
  - The design of the electrical system must account for these transients to prevent a trip of the NPP.





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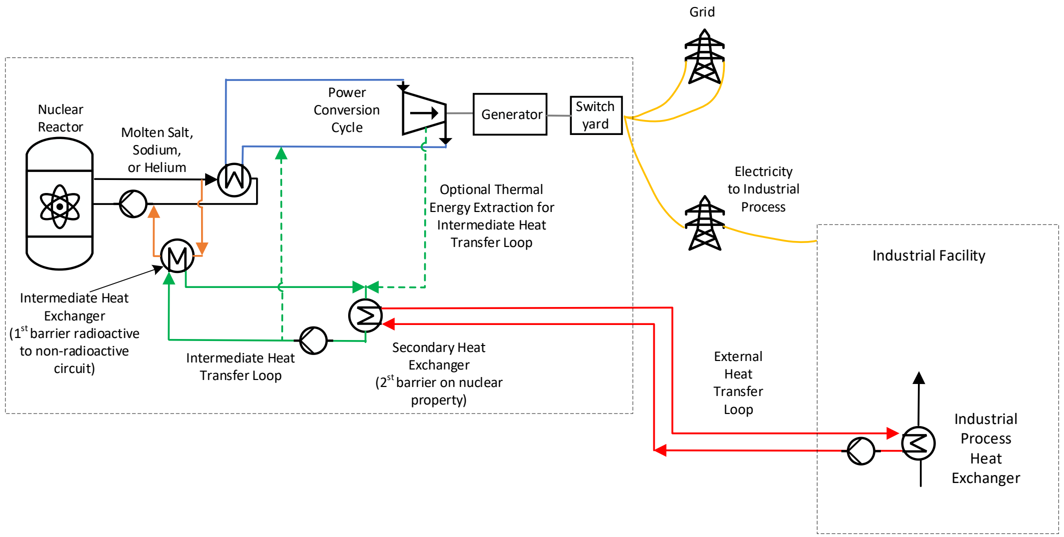
Safety Considerations – Accident Transients

- **Cross Contamination Transients**
  - Radioactive cross-contamination is considered a transient where radioactivity (e.g. Tritium) is unintentionally transferred from a radioactive system to a non-radioactive system (e.g. heat exchanger tube leakage).
  - Multiple barriers of isolation reduce the risk of cross-contamination, such as multiple heat exchanger barriers. Additionally online radiation detectors can be used to provide monitoring for radiation to limit any potential nuclear cross-contamination to the protected or owner-controlled area.



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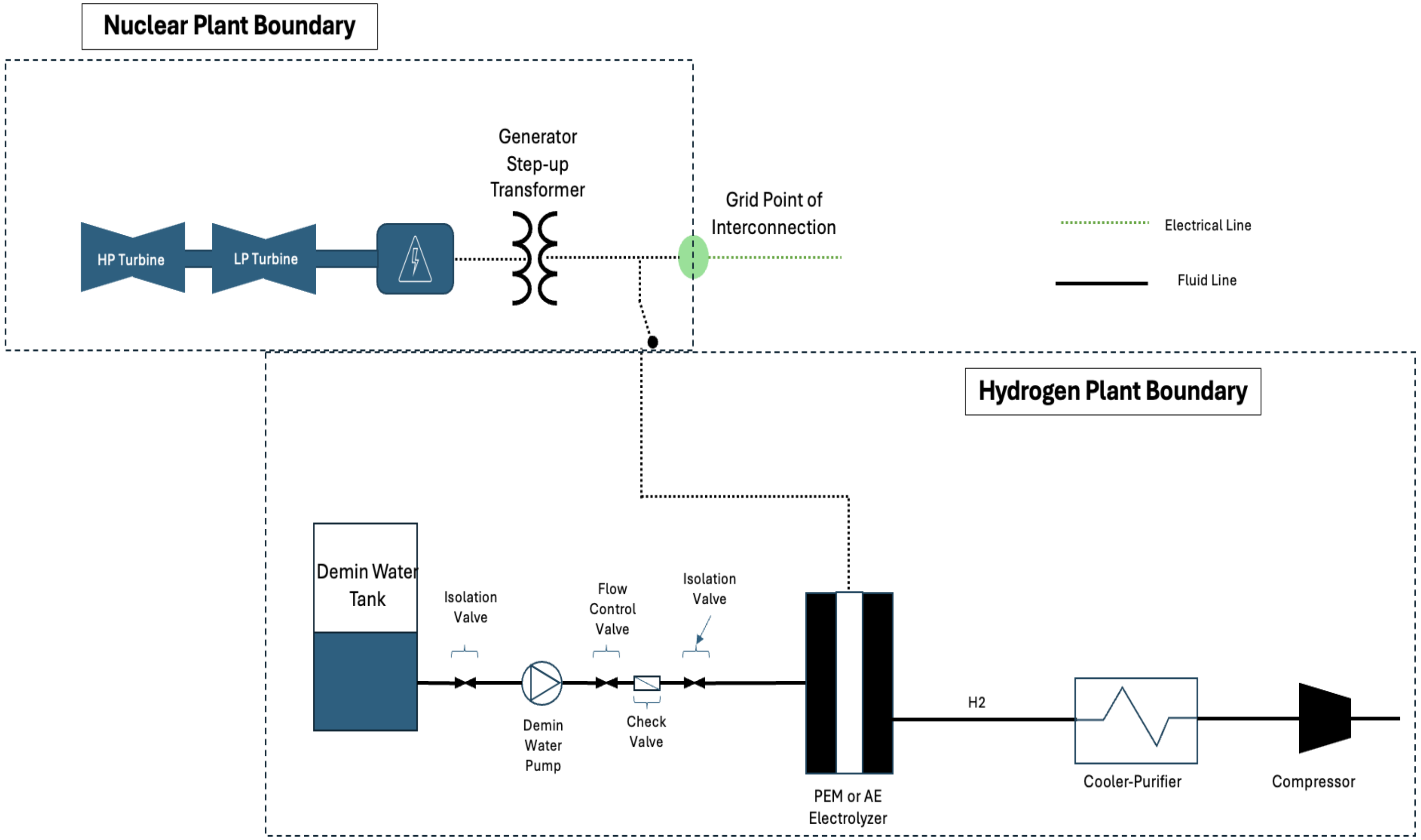
Backup Slides

Example - Alkaline and PEM Electrical Integration

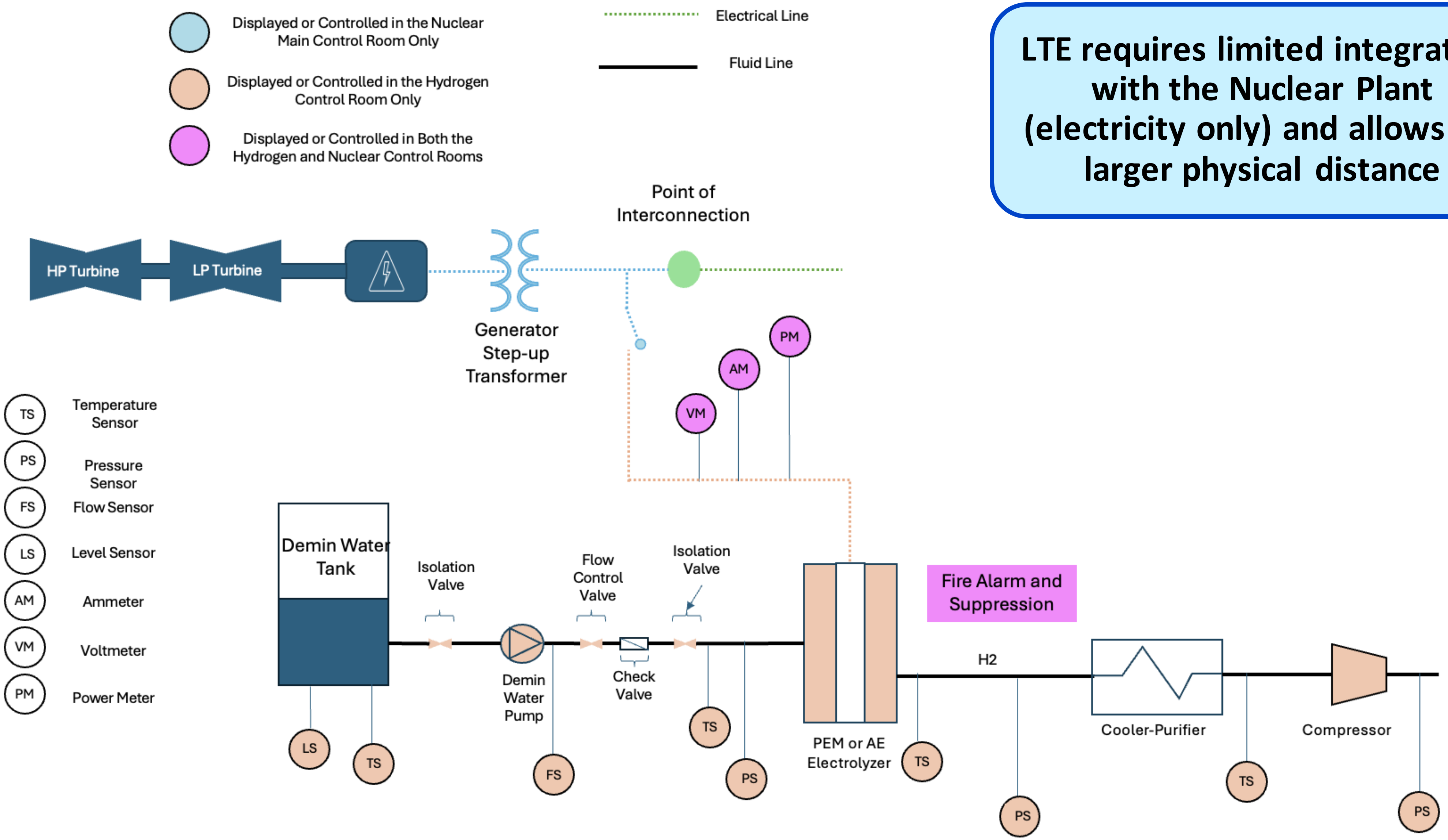
- Alkaline water electrolysis consist of two electrodes operating in a liquid alkaline electrolyte (Potassium hydroxide or sodium hydroxide at 25-40 wt%).

- Proton exchange membrane (PEM) electrolysis is the electrolysis of water in a cell equipped with a solid polymer electrolyte that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes.



LTE Integration is Electrically Driven

Example - Alkaline and PEM Control Integration



LTE requires limited integration with the Nuclear Plant (electricity only) and allows for larger physical distance

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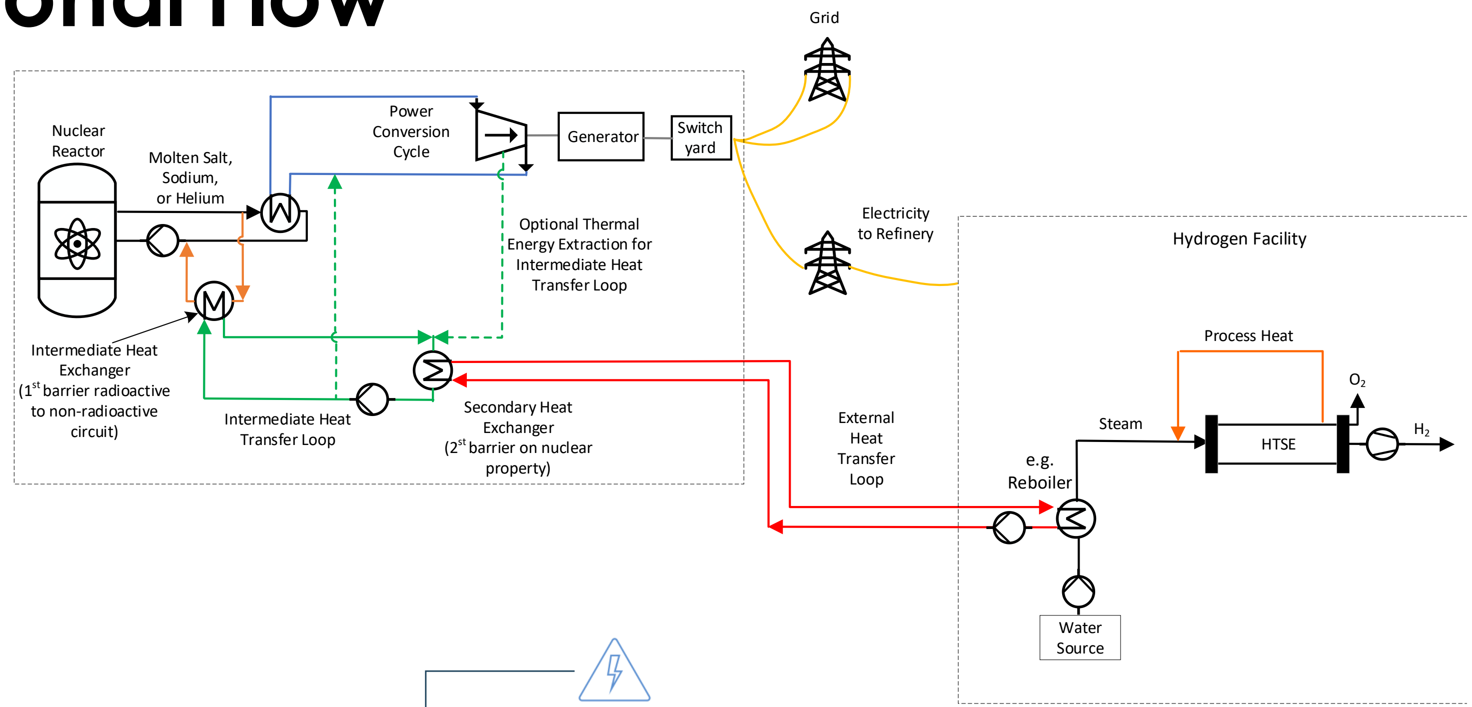
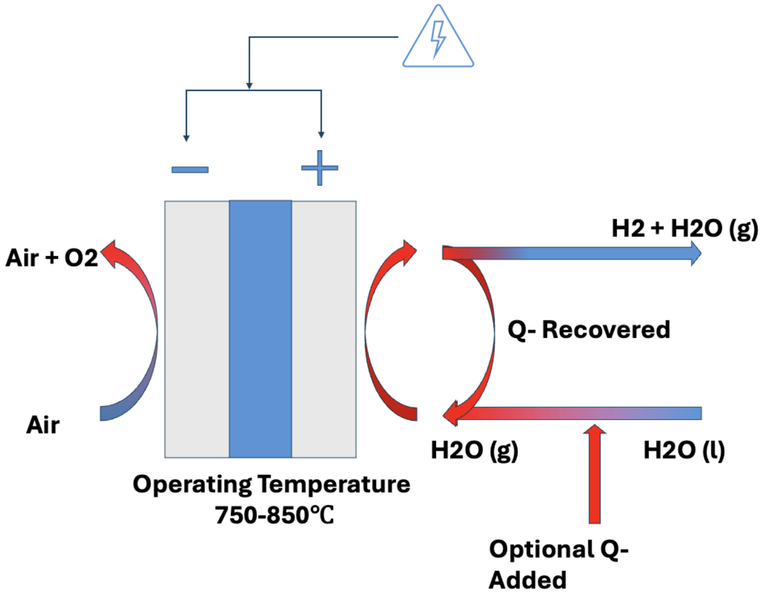
Example - SOEC Functional Flow

- Solid Oxide Electrolyzer Cell (SOEC) is a fuel cell that runs in regenerative mode to separate water by using a solid oxide, electrolyte to produce hydrogen and oxygen.

- Compared to Alkaline or PEM, SOEC uses steam as input. The heat of vaporization increases efficiency by ~5 kWh/kg.

- 40-60% of the thermal demand can be provided by heat recovery from stack.





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