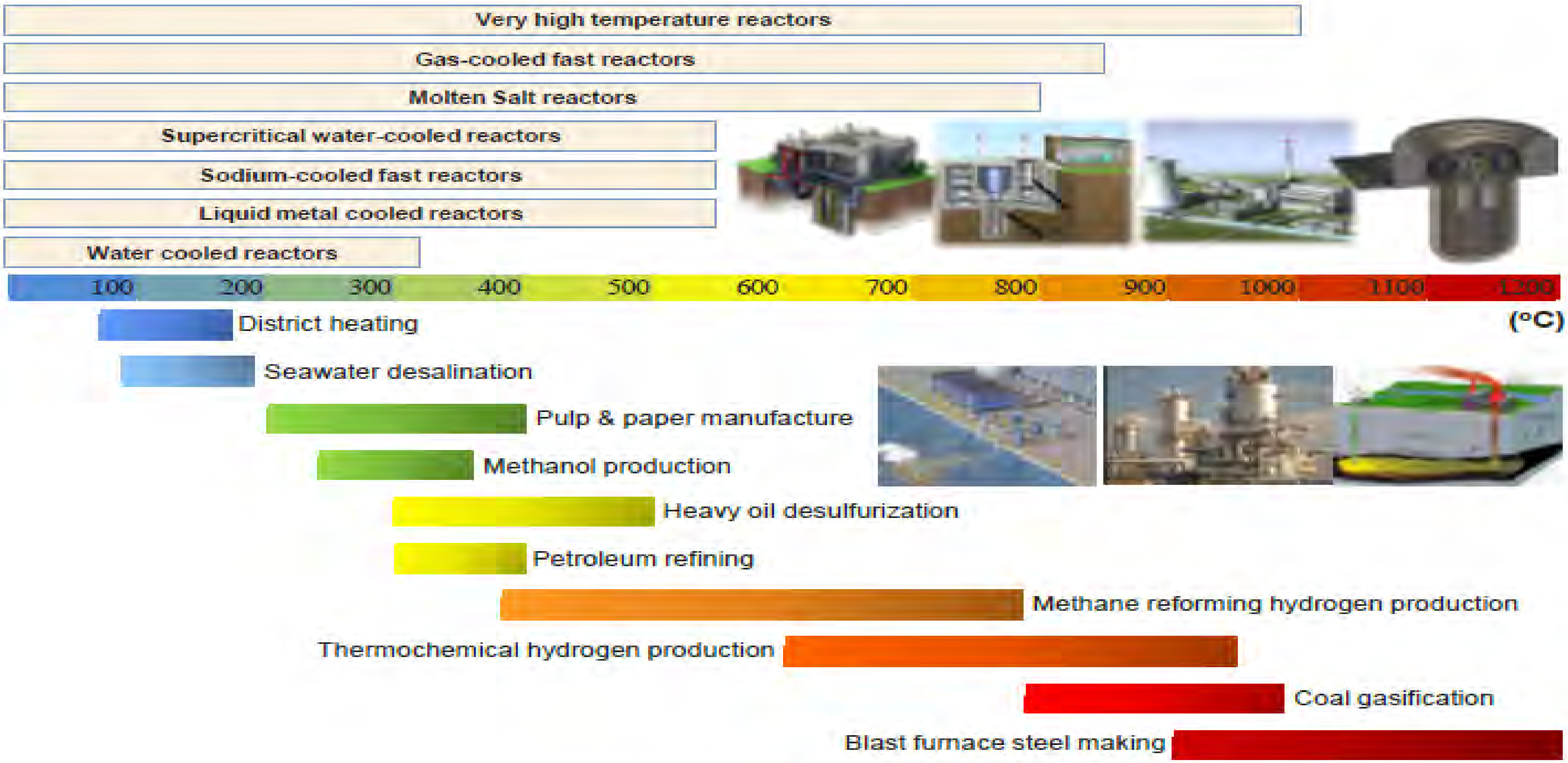
EA Sydney Division Nuclear Engineering Panel

Nuclear Power Reactors and Hydrogen Production

Tony Irwin

15th July 2020

Opportunities for Process Heat



Source: 2016 IAEA SMR Book

Nuclear Reactors for Hydrogen Production

Reactor Type	Outlet Temperature
Pressurised Water Reactor (PWR)	275ºC - 325ºC
Molten Salt Reactor (MSR)	600ºC - 800ºC
Very High Temperature Reactor (VHTR)	750ºC - 1,000 ºC

Temperatures of Electrolysis Technologies

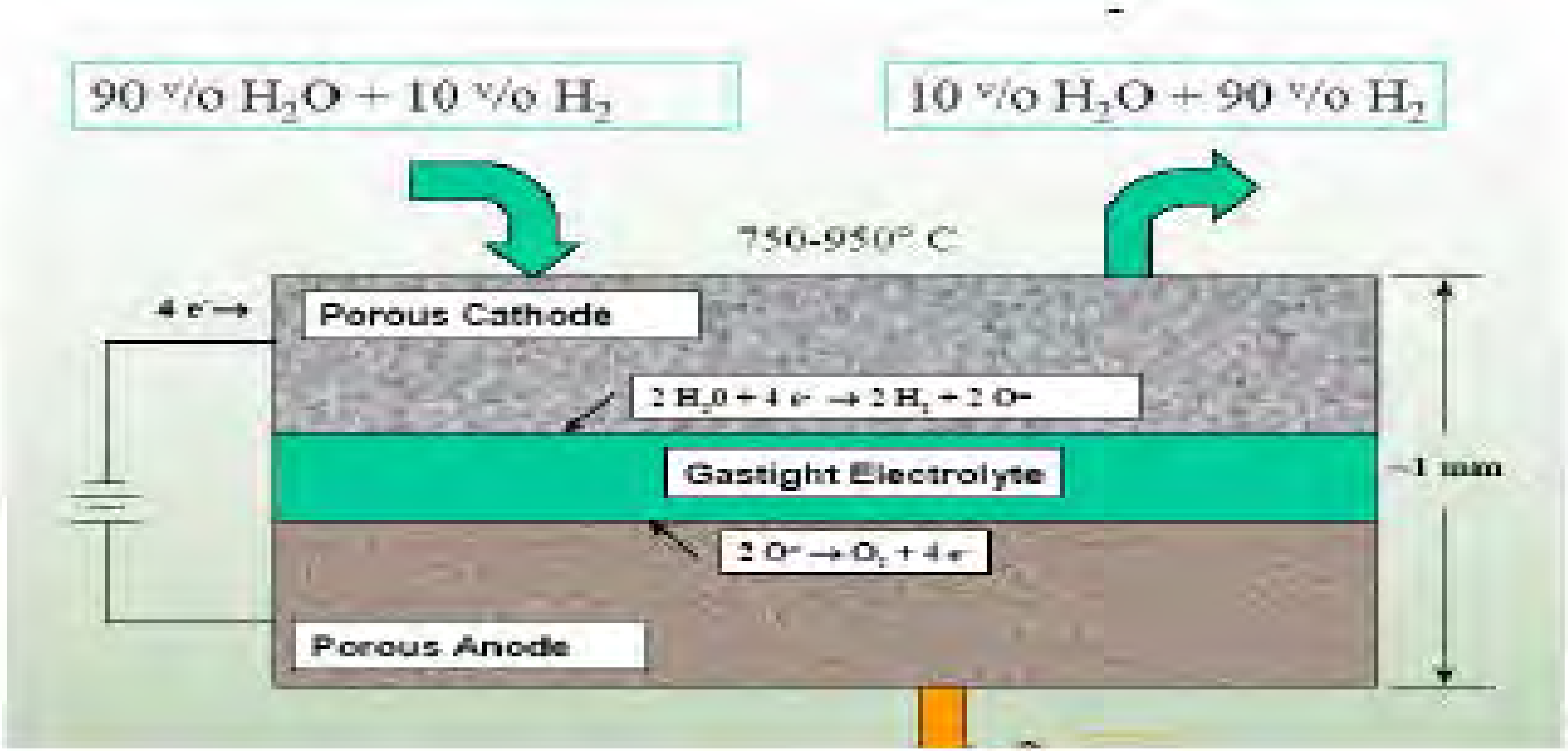
Electrolysis Technology	Temperature Range
Alkaline electrolysis (AE)	50ºC - 80ºC
Proton Exchange Membrane (PEM)	20ºC - 90ºC
Solid Oxide Electrolysis Cell (SOE)	700ºC – 1,000ºC

Source: for electrolysis temperatures : CSIRO 2016 Cost Assessment of H_2 Production from PV and Electrolysis

Temperatures of Chemical Technologies

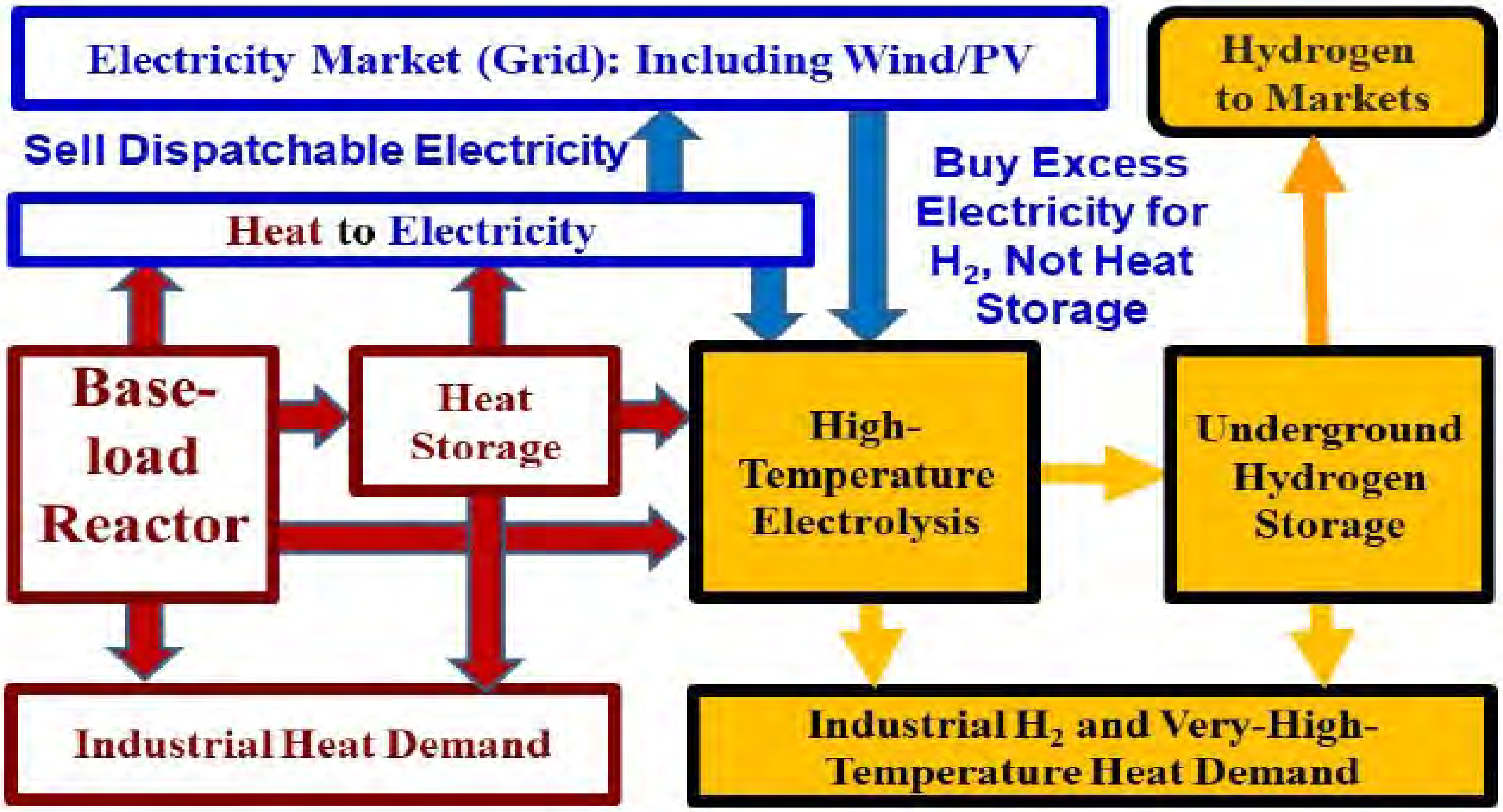
Chemical Technologies	Temperatures
Sulphur-Iodine	360ºC / 850ºC
Copper-chlorine	580ºC
Hybrid Sulphur	80ºC / 800ºC

High Temperature Steam Electrolysis



Solid oxide electrolyte.
More efficient than room temperature electrolysis because some of the energy is supplied as heat – operates at 750^{o}C – 950^{o}C
Countries actively developing: France (CEA), US (25 kW HTSE test facility at INL), China.

Nuclear Power and Hydrogen

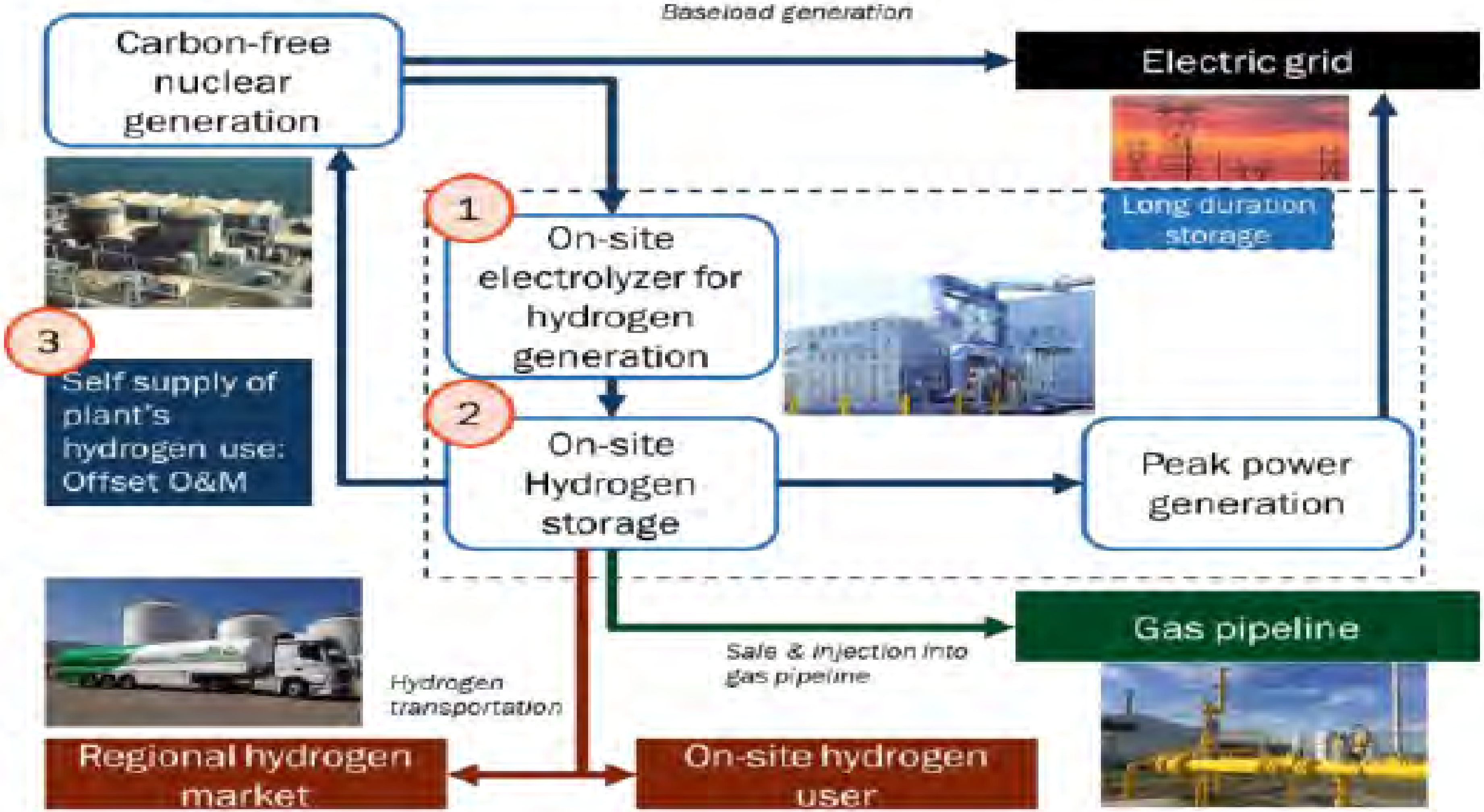


MIT/INL/EPRI May 2020

NICE Hydrogen webinar March 2020 – DOE H_2@Scale Initiative

Program Summary

Partners: Exelon & Nel Hydrogen, INL, NREL, ANL
Period: 36 months
Total budget: $7.2 million



Recently Funded NE-Led Demonstration

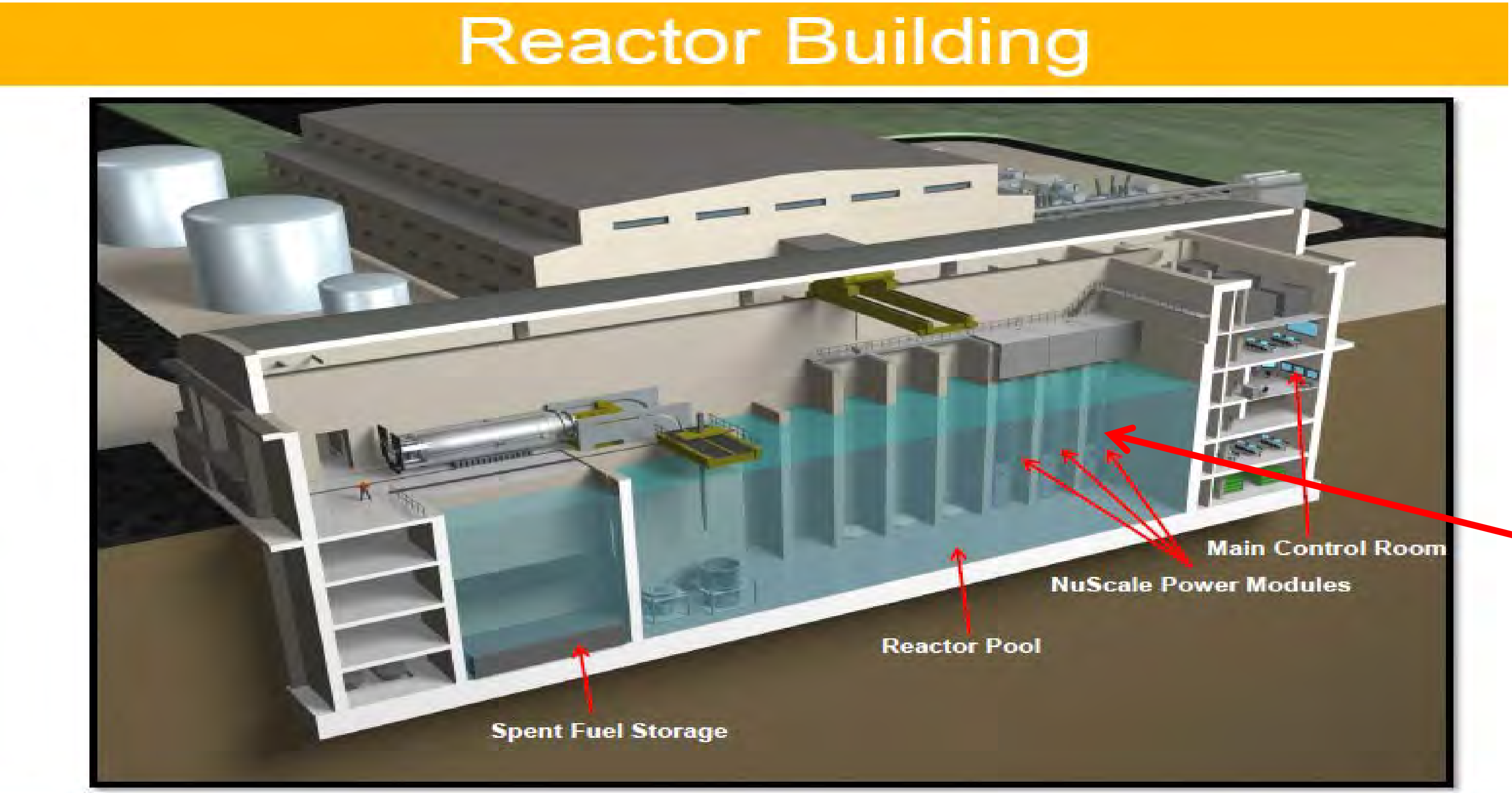
FirstEnergy Solutions Corp., Xcel Energy, APS, INL

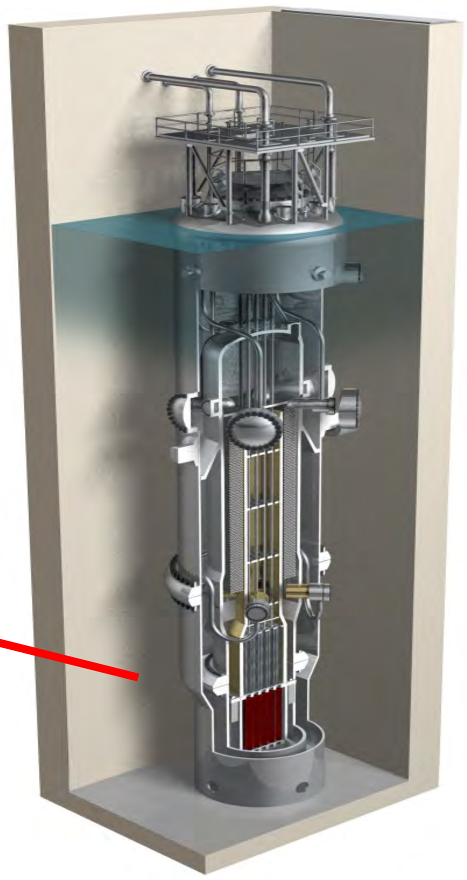
LWR Integrated Energy Systems Interface Technology Development & Demonstration at Davis-Besse NPP in Ohio

- $11.5M ($9.2M DOE), announced September 2019
- 2 MW Containerized "Turn-Key" Electrolysis Test Skid helps reduce project risk
- 24 month project - operation and verification planned for 2022
- Onsite and offsite uses planned

– Ensure no adverse effects on the plant, grid, or skid.
– Control software will be able to modulate H_2 output based on input variables.
– Control software will interface with Programmable Logic Computer (PLC) on vendor supplied H_2skid.

NuScale Power (USA) 60 MWe power modules





Main steam (3.5 MPa, 302^{o}C) to turbine and HTSE. 1.15 MWe electrical power used to boost inlet temperature to 800^{o}C.

Six module plant could produce 190 tonnes/day hydrogen

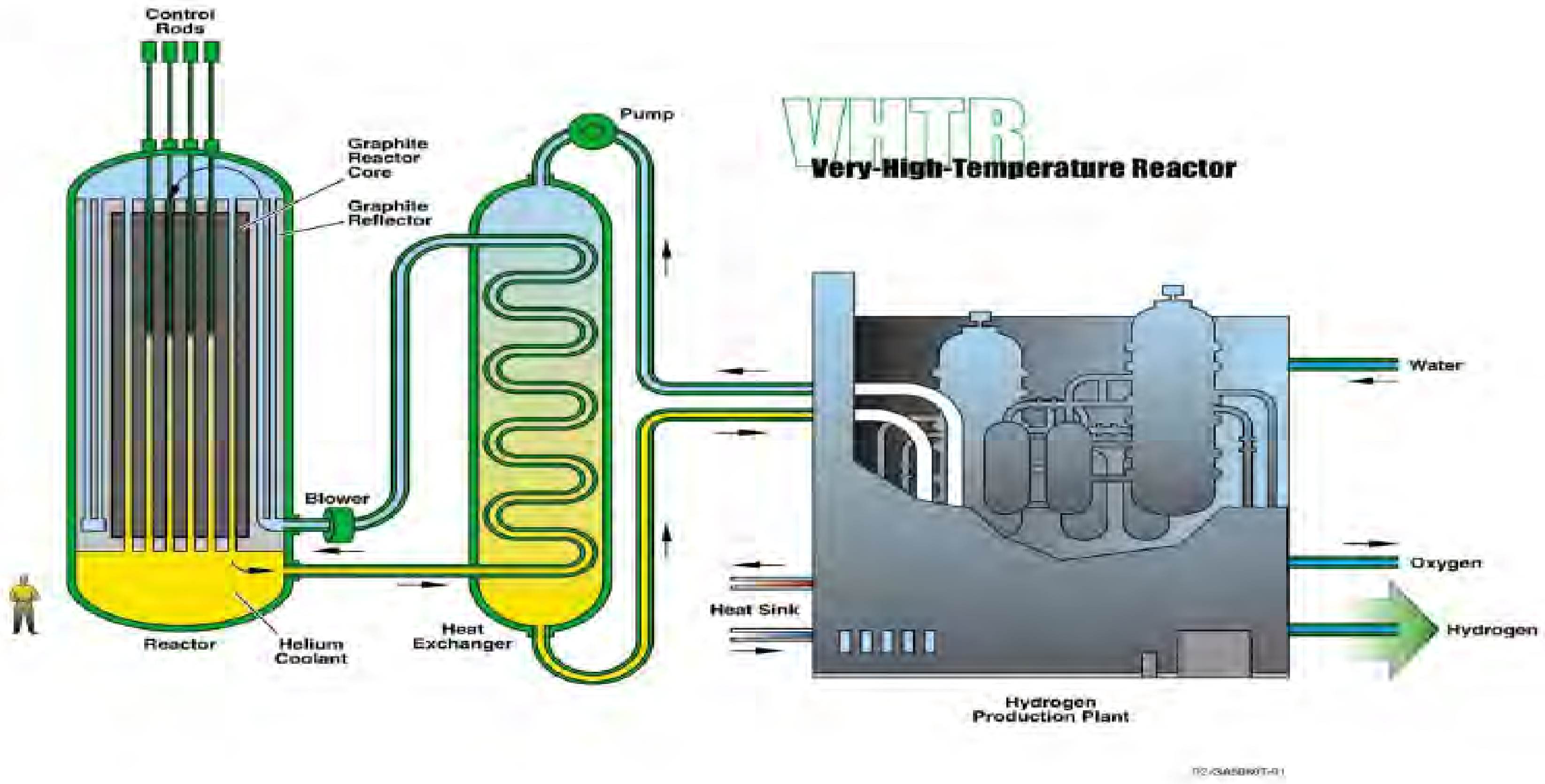
One module 1,310 kg/hr

Source: NuScale Power

Very-High-Temperature Reactor (VHTR)

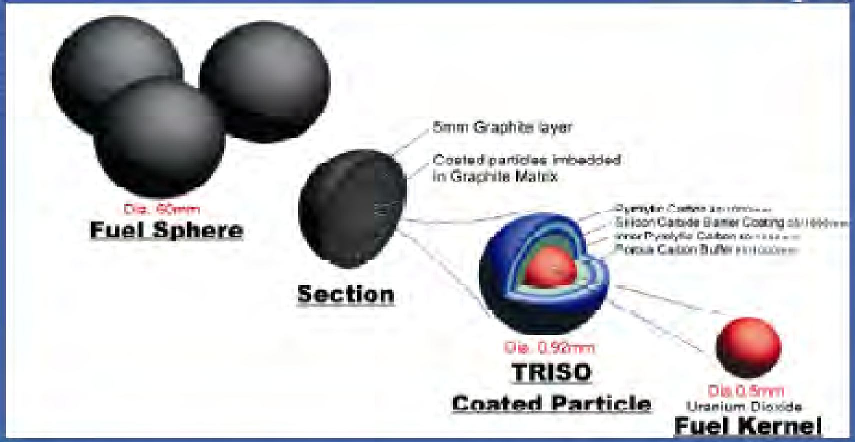
Characteristics
- He coolant
- >900C outlet temperature
- 250 MWe
- Coated particle fuel in either pebble bed or prismatic fuel

Benefits
- Hydrogen production
- Process heat applications
- High degree of passive safety
- High thermal efficiency option

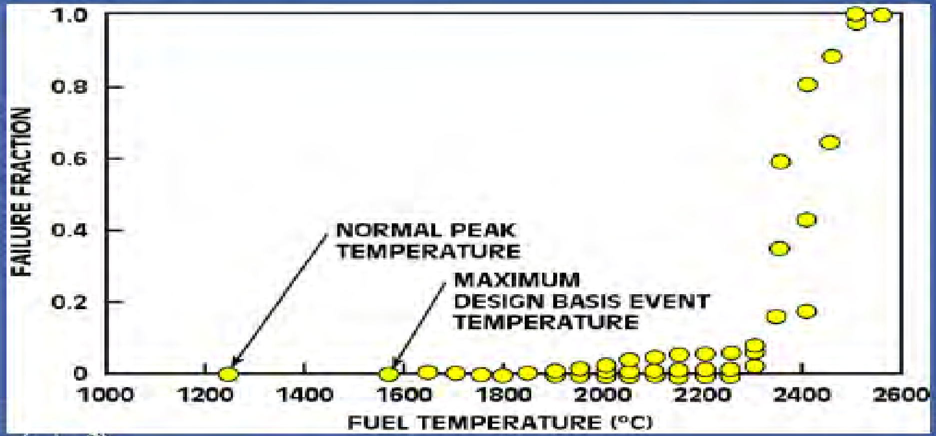


Inherent Safety Approach

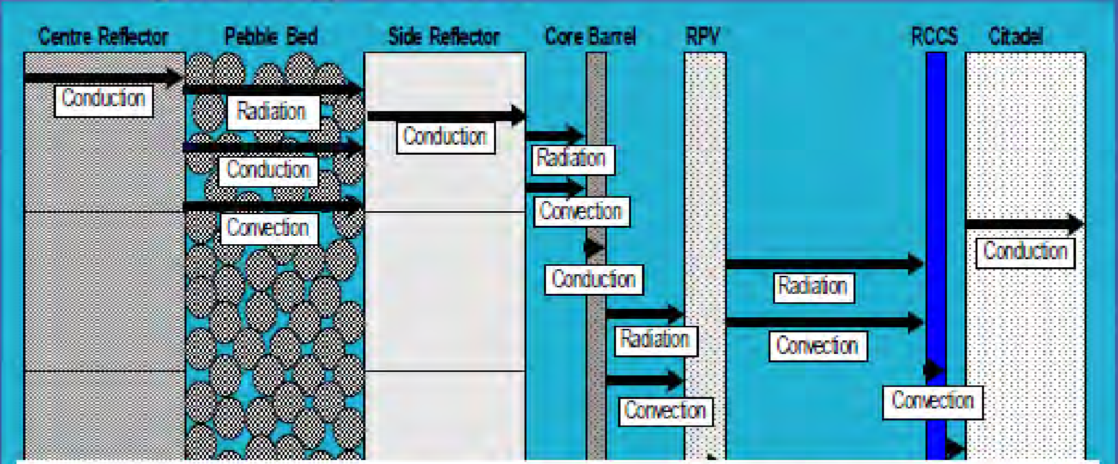
- Ceramic fuel retains radioactive materials up to ~2000˚C



- Coated particles stable to beyond maximum accident temperatures

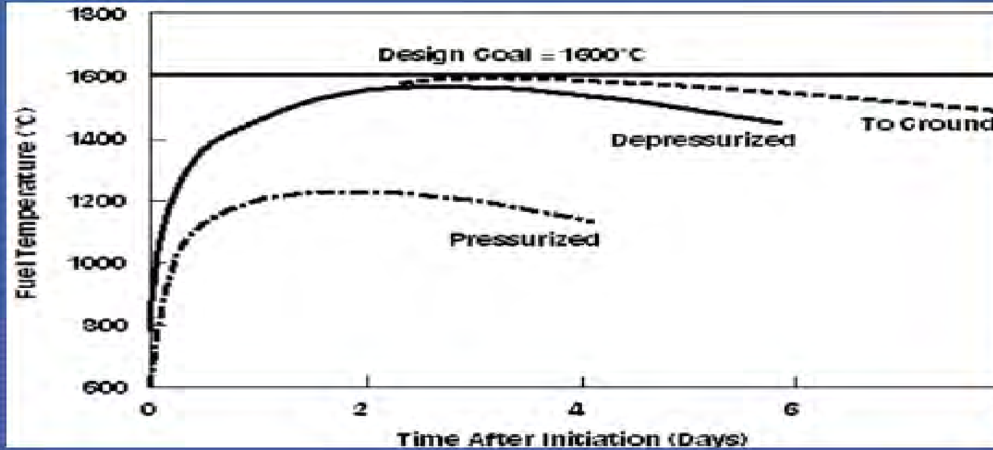


- Heat removed passively without primary coolant



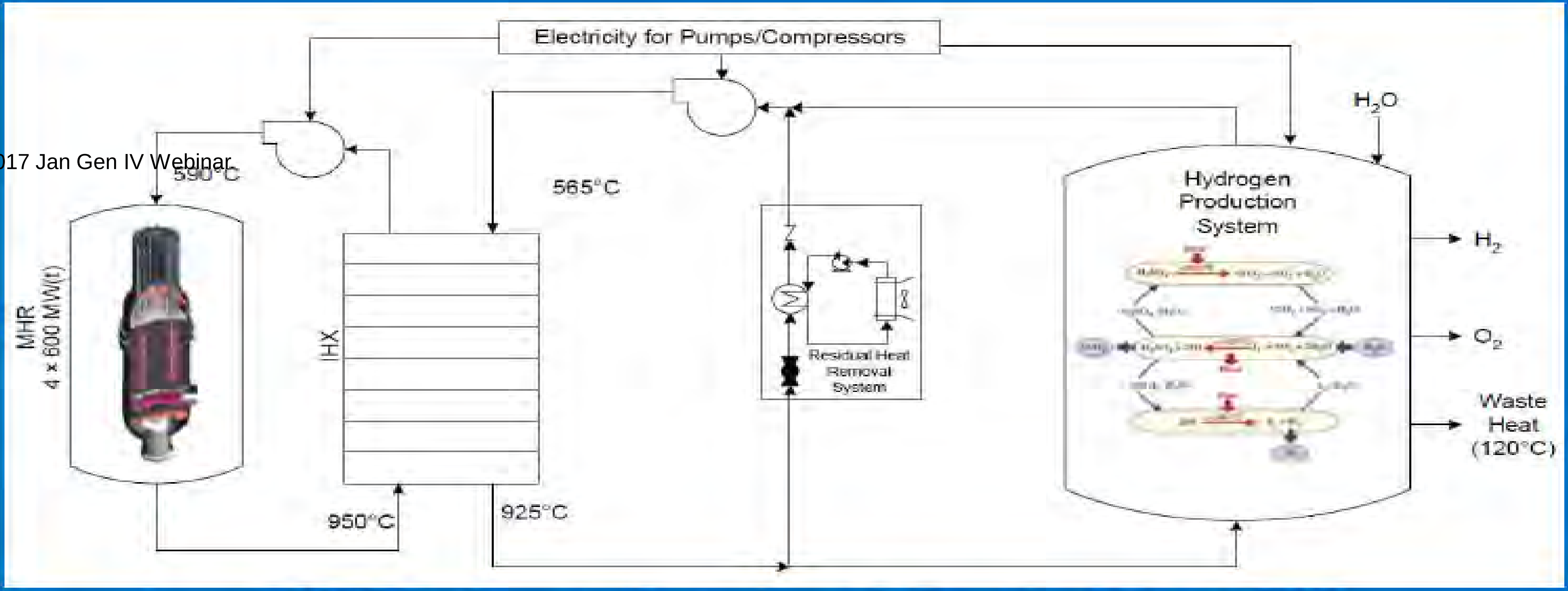
A meltdown is not possible!

- Fuel temperatures remain below design limits during loss-of-cooling events



IAEA

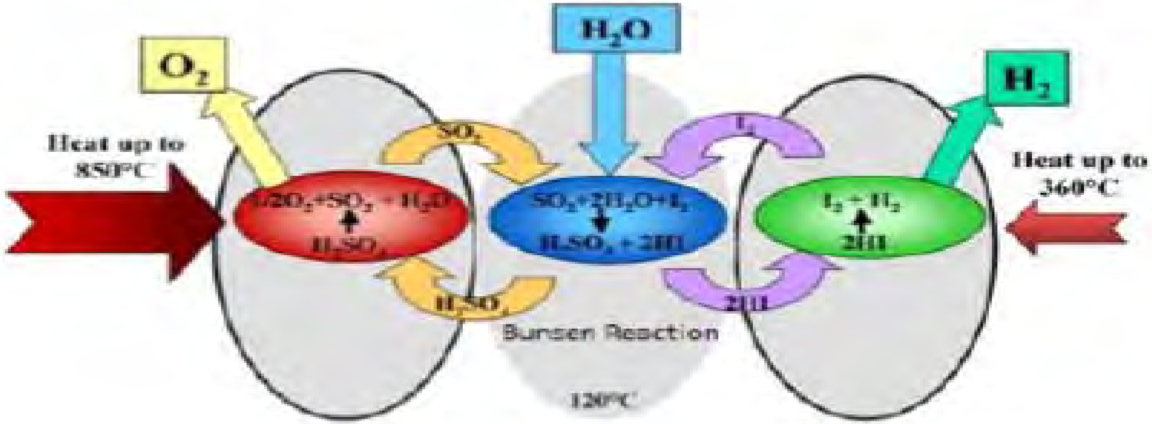
VHTR for Hydrogen Production



Source: "H2-MHR Pre Conceptual Design Report: S-I Based Plant" [Richards 2006]

2017 Jan Gen IV Webinar

Sulphur-Iodine Process
Countries actively developing:
Japan, China, South Korea, India.
Status: Integrated System demonstration (China 1 Nm^3/hr).
Also Japan 30l/hr



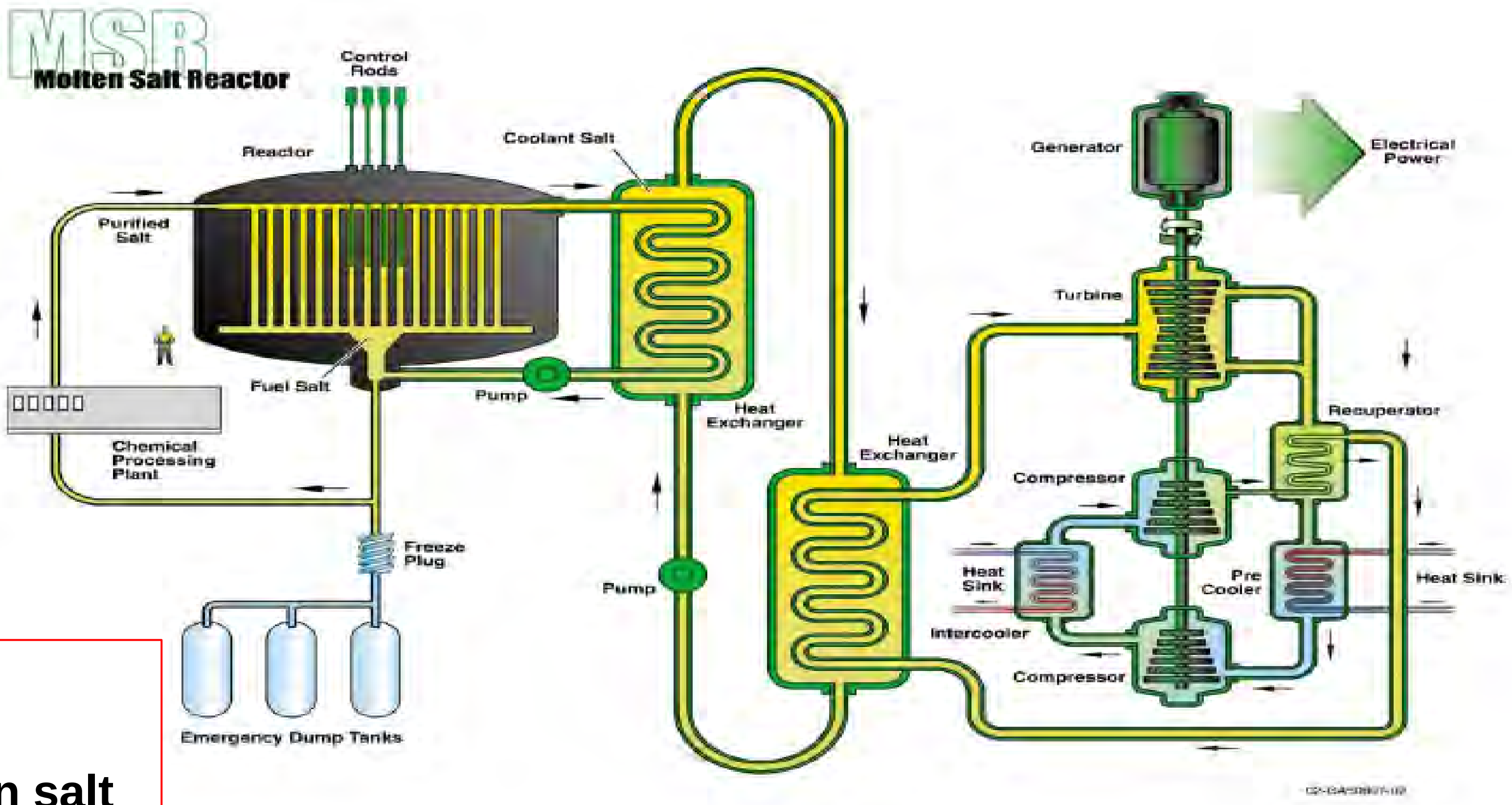
Molten Salt Reactor (MSR)

Characteristics

- Fuel is liquid fluorides of U and Pu with Li, Be, Na and other fluorides
- 700–800C outlet temperature
- 1000 MWe
- Low pressure (<0.5 MPa)

Benefits

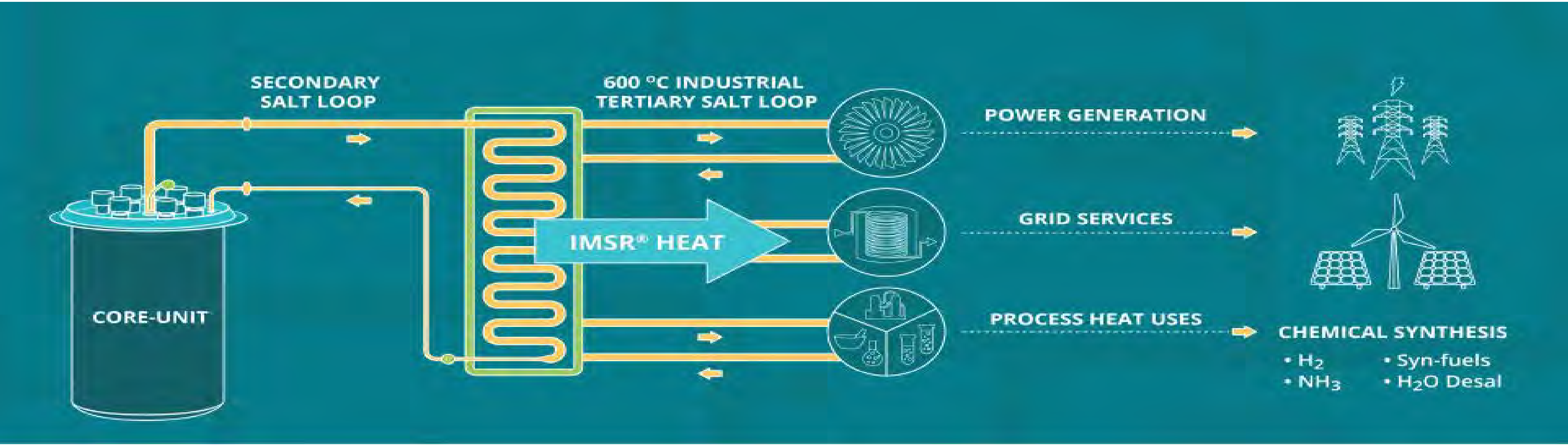
- Waste minimization
- Avoids fuel development
- Proliferation resistance through low fissile material inventory



Challenges

- **Corrosion**
- **Freezes at 320^{o}C-500^{o}C depending on salt**
- **Significant fraction of the fuel is outside the core**
- **Significant decay heat around the circuit**

Terrestrial Energy
Integral Molten Salt Reactor (IMSR)



400 MWTh, 190 MWe, load following capable plus 600^{o}C process heat
Build in 4 years, 24 hectare site, first deployment 2020's , looking at sites at Canadian National Laboratories and INL.
LCOE US$50/MWhr
CNSC (Canadian Nuclear Safety Commission) Phase 1 design review completed, Phase 2 in progress
26 June 2017 – GAIN (Gateway for Accelerated Innovation in Nuclear) award from US-DOE
Developing hydrogen production using hybrid Sulphur process

The Future: Microreactor Powered Hydrogen Fueling Station

Notional Specs*

MW Total (15 MW modules)	60
kg / day trucks	50
kWh / kg hydrogen generation	50
kWh / truck / day	2500
trucks / station / day	576
fueling positions	~12

*not associated with images

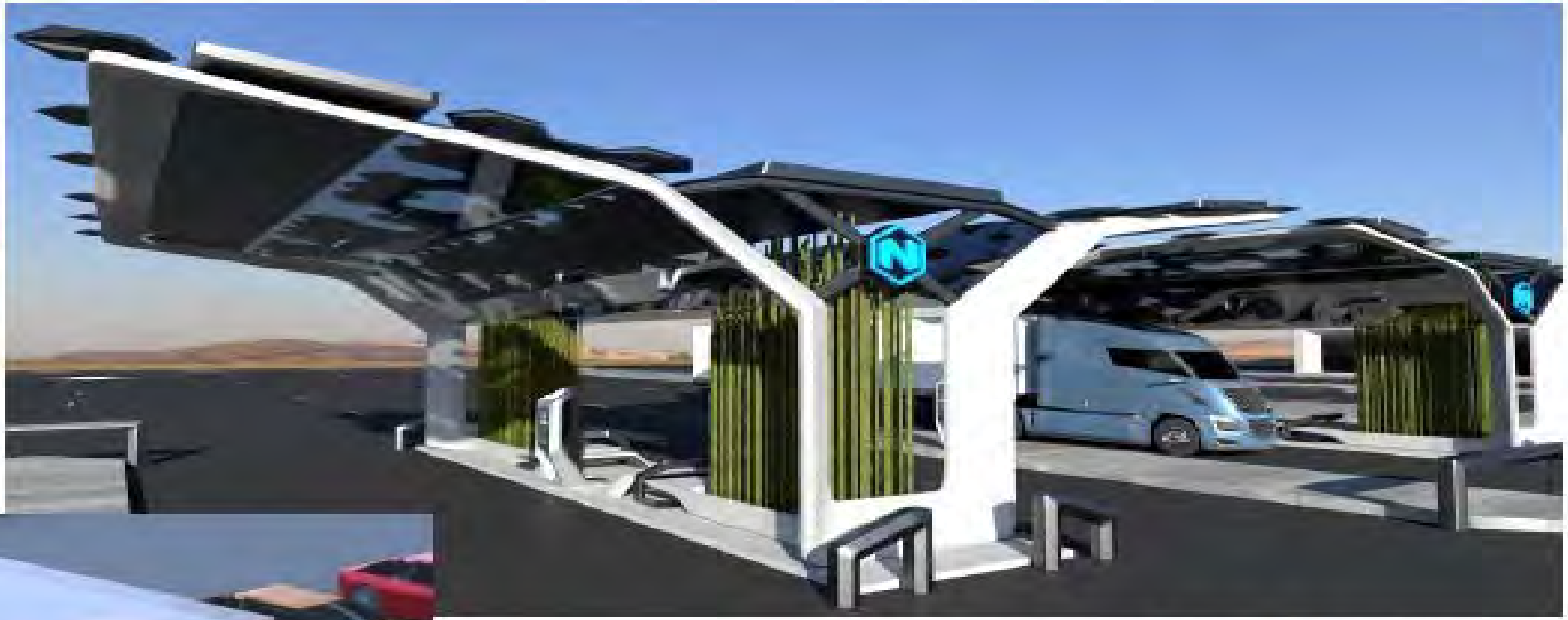


Image courtesy of Nikola Motor Company

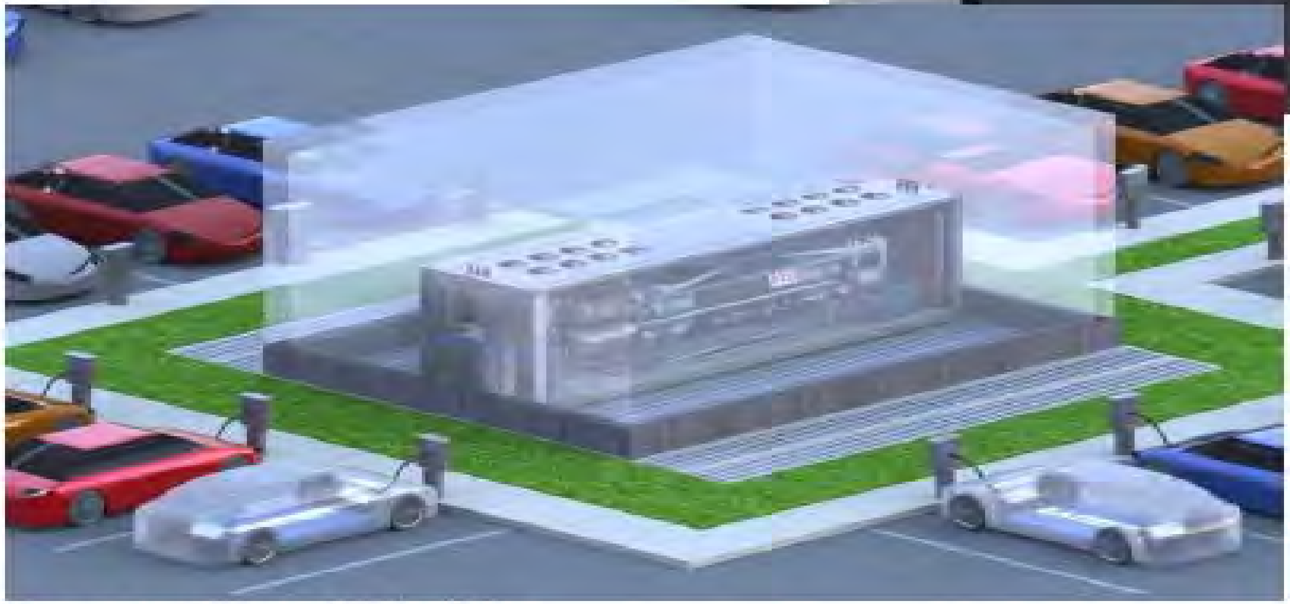


Image courtesy of HolosGen

HOLOS Microreactor
VHTR TRISO fuel in sealed cartridges, helium or CO_2 coolant to Brayton power conversion gas turbine.
Heat and electricity for electrolyser.

Conclusions

Nuclear Power is the only low emissions, reliable technology that can provide substantial quantities of process heat.

A change to low emissions heat for industrial processes will be an essential part of Australia’s drive to low emissions by 2050.

The current fleet of nuclear power plants could use surplus electricity to produce hydrogen

Advanced nuclear plants coupled with higher temperature more efficient hydrogen production technology will be a cost-effective source of hydrogen with low emissions and minimum land requirements.