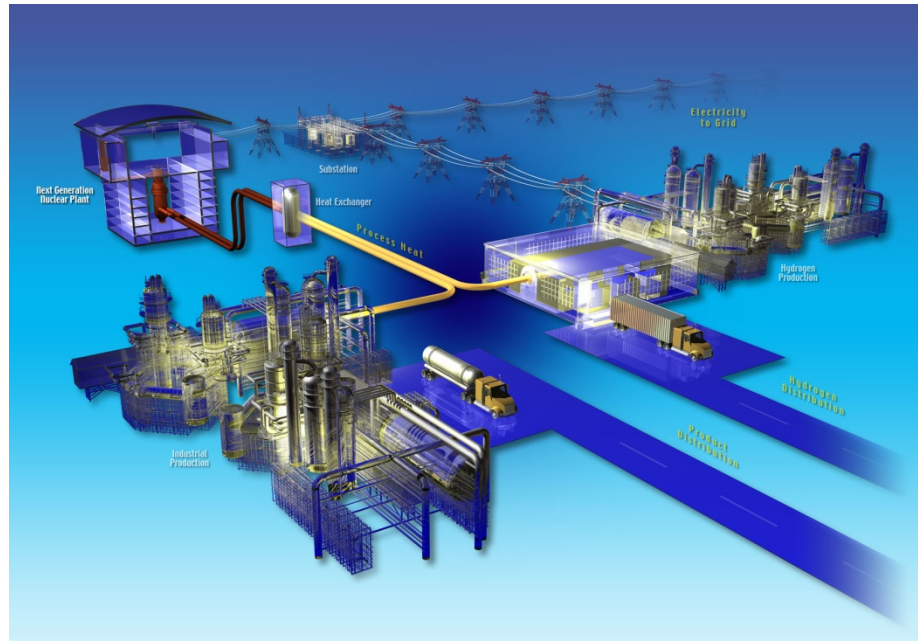


# Systems Engineering Provides Successful High-Temperature Steam Electrolysis Project

June 20, 2011

Charles Park, PE, CSEP, PMP  
Systems Engineer  
Idaho National Laboratory

[www.inl.gov](http://www.inl.gov)

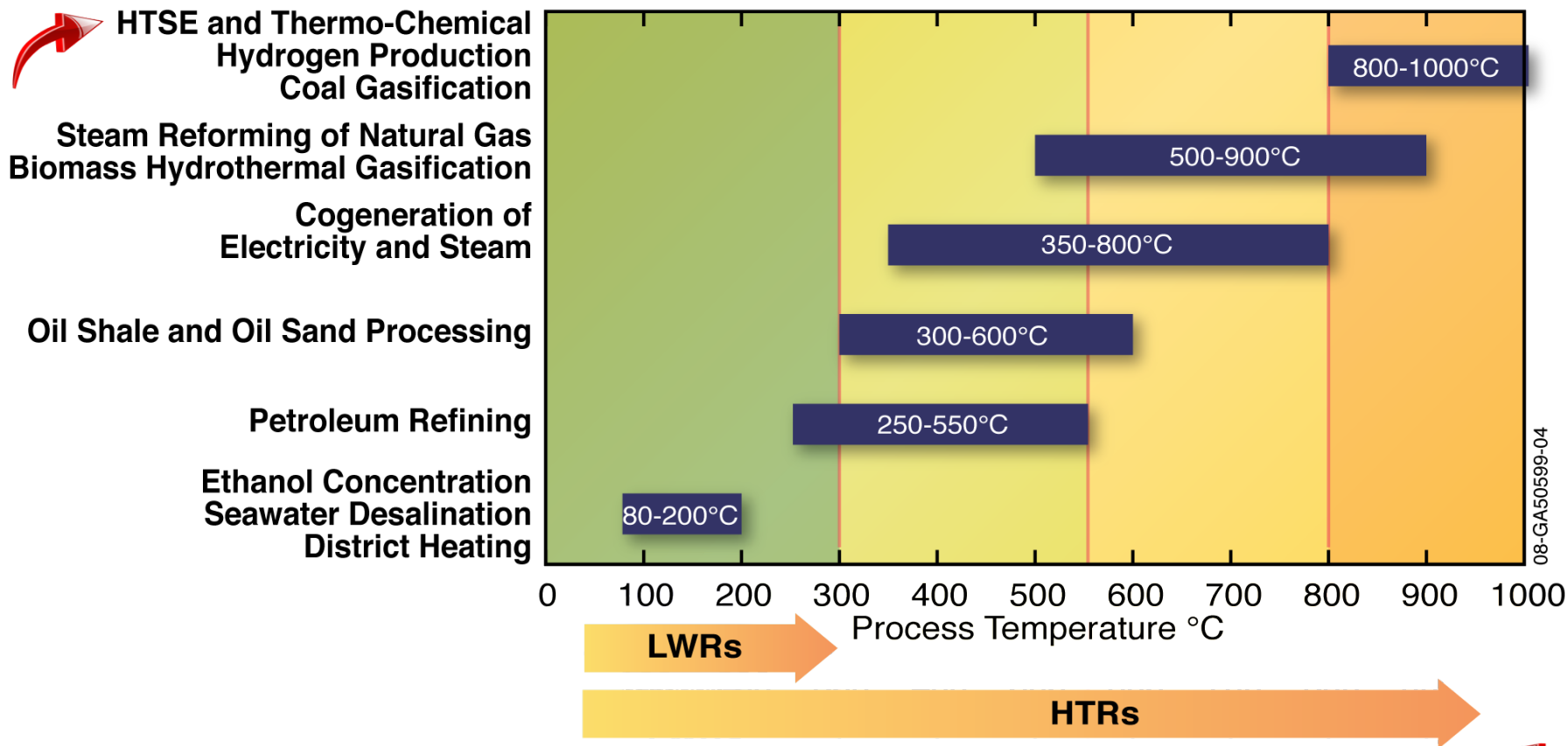


# Idaho National Laboratory (INL) Accomplishments

- Established in 1949
- Develop Navy nuclear propulsion systems and operator training
- Reprocess Navy Nuclear Fuel
- Design, construct and operate 52 nuclear reactors
- Produce key medical and industrial isotopes
- One of DOE's 10 multi-program labs
- DOE's designated lead lab for nuclear energy
- 8,000+ workers
- 890 Square Miles
- Develop nuclear reactor safety code
- Tank armor production
- NASA program support
- Completed significant Decommissioning
- Converted over 8 million gallons of liquid high level radioactive waste to 4,400 m<sup>3</sup>

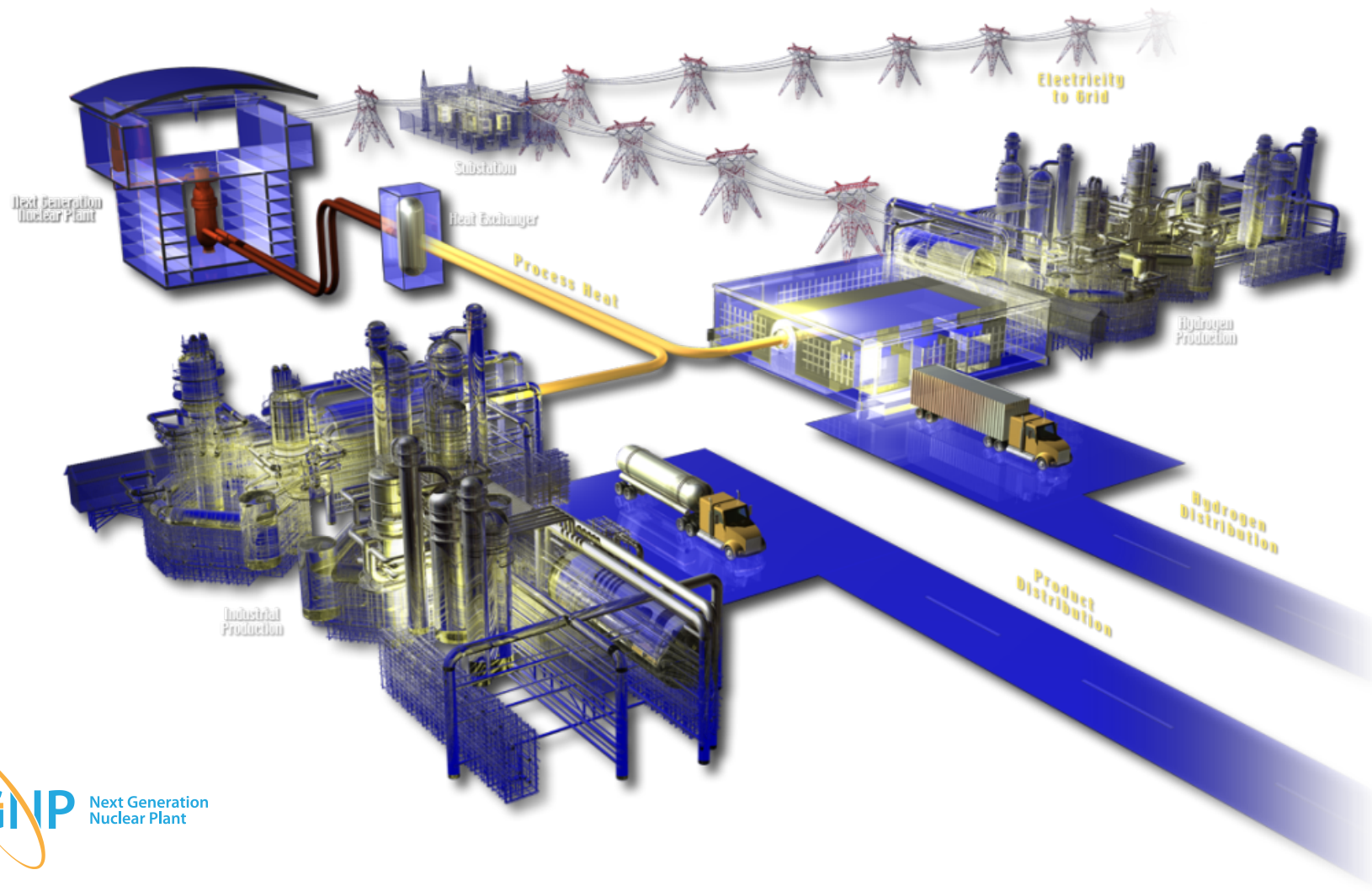


# Beyond Electricity – Applications of High Temperature Gas Reactors (HTGRs)



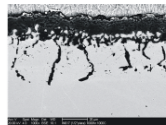
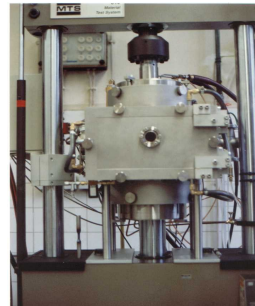
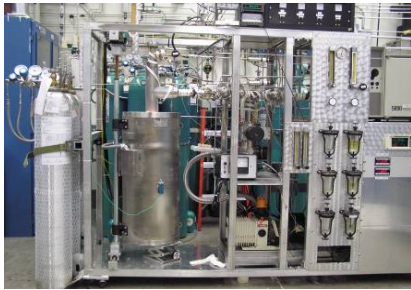
High Temperature Gas Reactors can provide energy production that supports many industrial applications including petrochemical and petroleum industries

# ***Next Generation Nuclear Plant (NGNP): Enables Nuclear Energy to Enter Other Markets Beyond Electricity Including: Process Heat, Hydrogen, and Electricity***





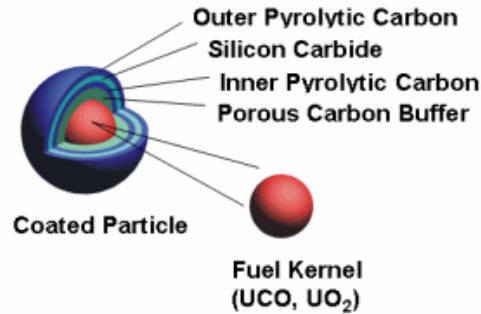
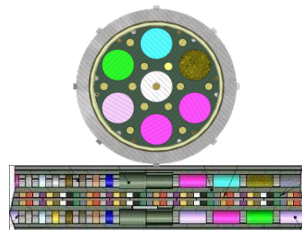
# NGNP Technology Development



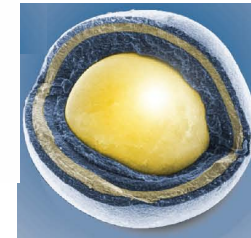
High Temperature Materials



Graphite Development



## Fuel Fabrication, Irradiation, and Safety Testing



## Triso Fuel Particle

~3mm

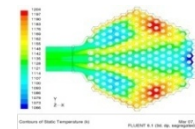
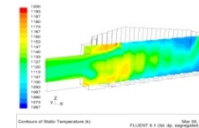
<10<sup>-5</sup>

Failures at  
1,600 °C

Captures  
Fission  
Products

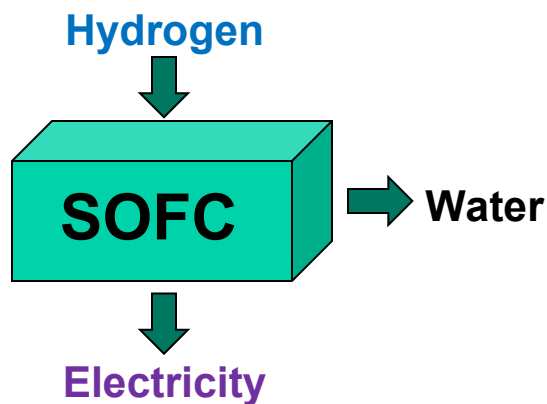


## Design and Safety Methods Development

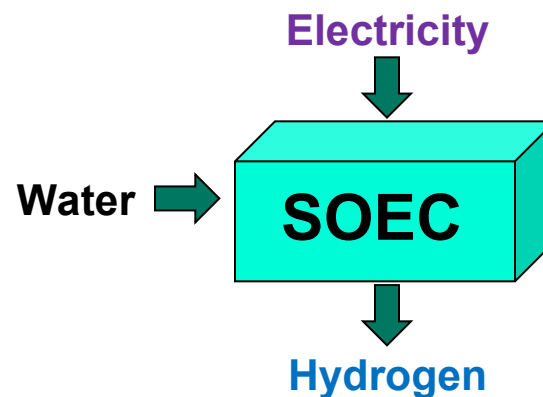


# ***Solid Oxide Fuel vs Electrolysis Cells***

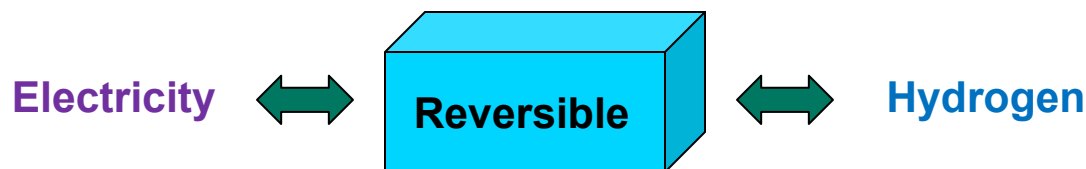
*(High efficiency, long-term stability, fuel flexibility, low emissions, low cost, but higher temperature and material compatibility issues)*



**Developing Technology**  
(Rolls Royce, Ceres Power)



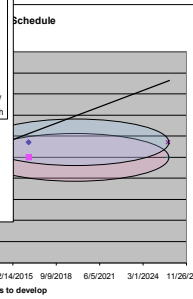
**Emerging Technology**  
(INL HTSE)



**“ Holy Grail “**

# SE Applications for Successful HTSE

- Rigorous, transparent down-selection of H<sub>2</sub> production technologies



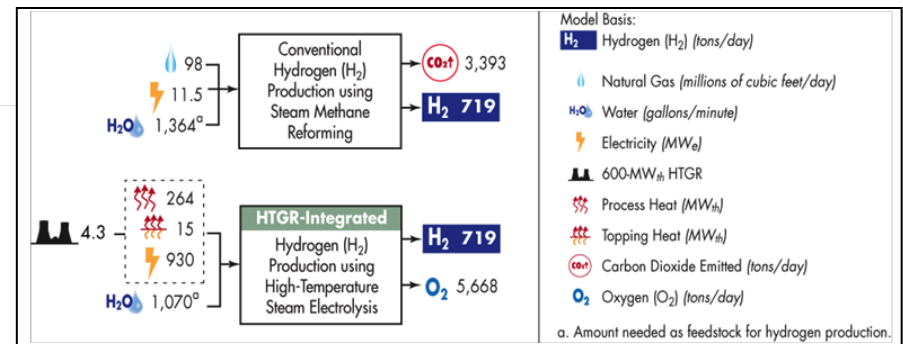
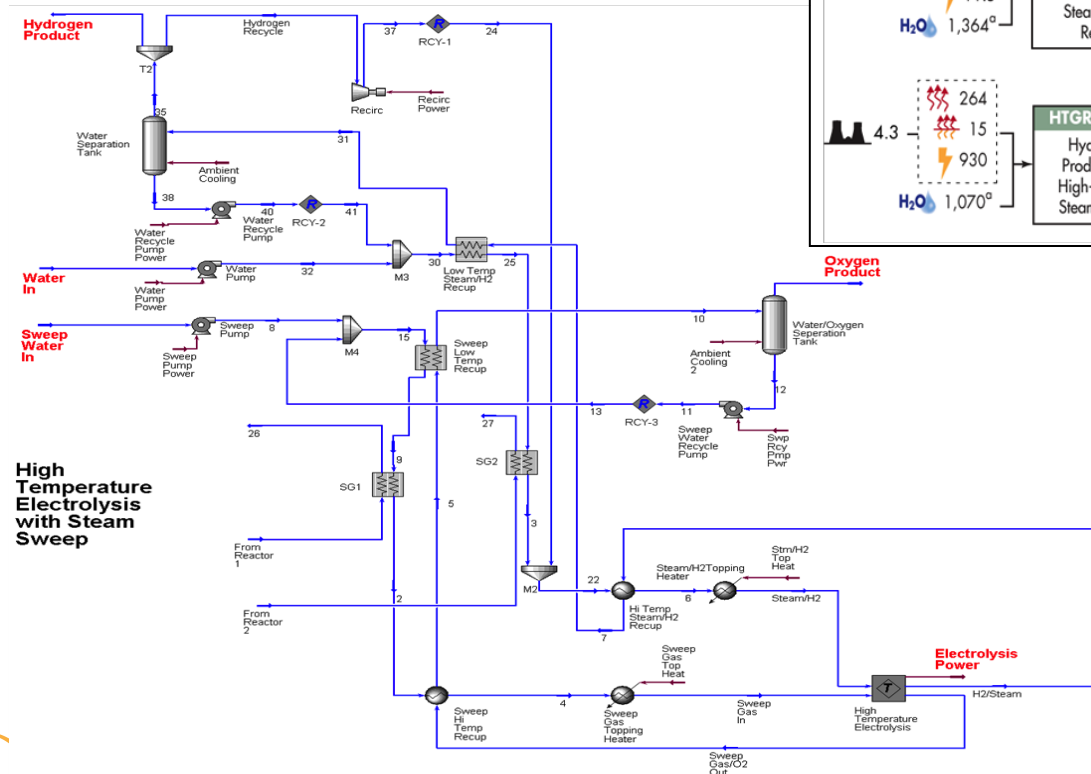
Criteria	SI	HTSE	SI-Low	SI-High	HTSE-Low	HTSE-High	Comments
Process Reliability (90%)	1	1	1	1	1	1	Availability during Operations (Sec 4.4)
Life cycle and life cycle cost	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Contamination Control	1	1	1	1	1	1	Purity of Hydrogen (Sec 4.1)
Efficiency	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Operating cost (unit temperature)	1	1	1	1	1	1	Operating Assumptions and Comments (Sec 3)
Life Cycle	1	1	1	1	1	1	Purity of Hydrogen (Sec 4.1)
Waste	1	1	1	1	1	1	Waste Management (Sec 4.4)
Availability	1	1	1	1	1	1	Availability during Operations (Sec 4.4)
Operational safety	1	1	1	1	1	1	Operating Assumptions and Comments (Sec 3)
HT Storage and Distribution	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Material Availability	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Life cycle cost	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Availability	1	1	1	1	1	1	Availability during Operations (Sec 4.4)
Operating Assumptions and Comments (Sec 3)	1	1	1	1	1	1	Operating Assumptions and Comments (Sec 3)
Technology Maturity (Sec 4.7)	1	1	1	1	1	1	Technology Maturity (Sec 4.7)
Availability during Operations (Sec 4.4)	1	1	1	1	1	1	Availability during Operations (Sec 4.4)
Cost of Hydrogen (Sec 4.1)	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Development Risk (Sec 4.8)	1	1	1	1	1	1	Development Risk (Sec 4.8)
Flexibility to serve various Applications (Sec 4.9)	1	1	1	1	1	1	Flexibility to serve various Applications (Sec 4.9)
Operating Assumptions and Comments (Sec 3)	1	1	1	1	1	1	Operating Assumptions and Comments (Sec 3)
Availability during Operations (Sec 4.4)	1	1	1	1	1	1	Availability during Operations (Sec 4.4)
Cost of Hydrogen (Sec 4.1)	1	1	1	1	1	1	Cost of Hydrogen (Sec 4.1)
Development Risk (Sec 4.8)	1	1	1	1	1	1	Development Risk (Sec 4.8)
Technology Maturity (Sec 4.7)	1	1	1	1	1	1	Technology Maturity (Sec 4.7)

Goals	Criteria	Wt%	Worse <----- Scoring -----> Better					Comment	Ratings			Score		
			1	2	3	4	5		HTSE	HyS	SI	HTSE	HyS	SI
Performance (35%)	Quantity of H <sub>2</sub> Produced	10%	<10	10-12	12-15	15-20	>20	1,000's kg/day	3	2	2	0.3	0.2	0.2
	Purity of Hydrogen	5%	None	Almost none	Some	Most	All	Independent of Need	5	3	4	0.25	0.15	0.2
	Serve Various Applications	15%	Useless	Almost none	Some	Most	All	Demand circa 2009	4	4	3	0.6	0.6	0.45
	Waste Management	5%	Extreme	Significant	Typical	Modest	None	Industrial & Hazardous	4	3	2	0.2	0.15	0.1
Cost (30%)	Cost of Production	10%	>9	7-9	5-7	3-5	<3	\$/kg	3	3	2	0.3	0.3	0.2
	Cost Uncertainty	10%	Unrealistic	Optimistic	Consistent	Conservative	Very Conservative	Confidence in scoring	3	3	2	0.3	0.3	0.2
	Development Cost (Relative)	10%	>1,200 (very high)	1,000-1,200 (high)	800-1,000 (medium)	600-800 (med-low)	<600 (low)	\$M	4	3	2	0.4	0.3	0.2
	Risk (35%)	15%	<2.5	2.5-3.4	3.5-4	4.1-4.5	>4.5	Composite	3	2	1	0.45	0.3	0.15
	Development Risk	20%	Insurmountable	High	Medium to High	Low to Medium	Low	Composite	3.5	3	2	0.7	0.6	0.4
Total									32.5	26	20	3.5	2.9	2.1

Out of 5

# SE Applications for Successful HTSE

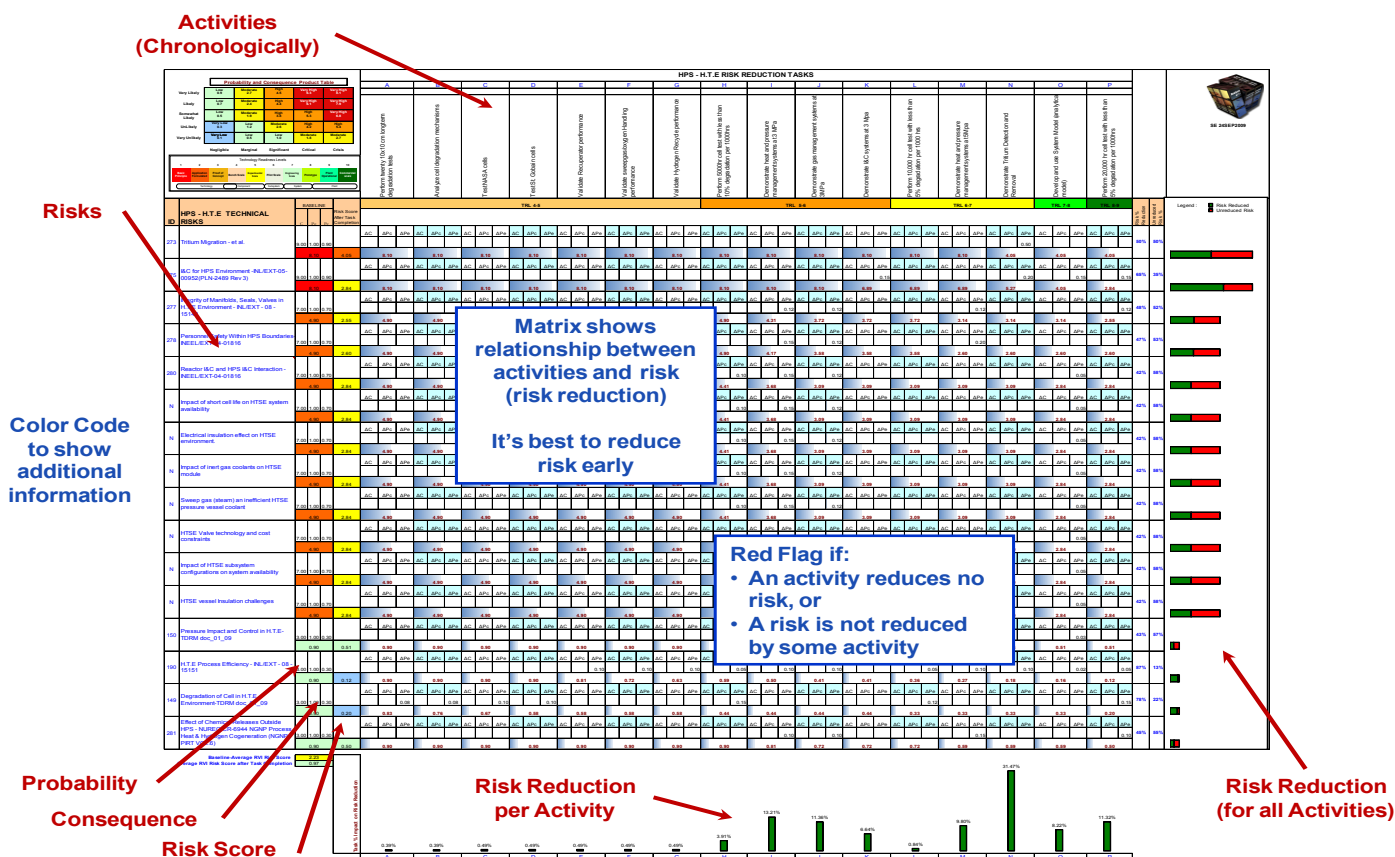
- Rigorous, transparent down-selection of H<sub>2</sub> production technologies
- HTSE Flowsheets integrated with industrial process applications





# SE Applications for Successful HTSE

- Rigorous, transparent down-selection of H<sub>2</sub> production technologies
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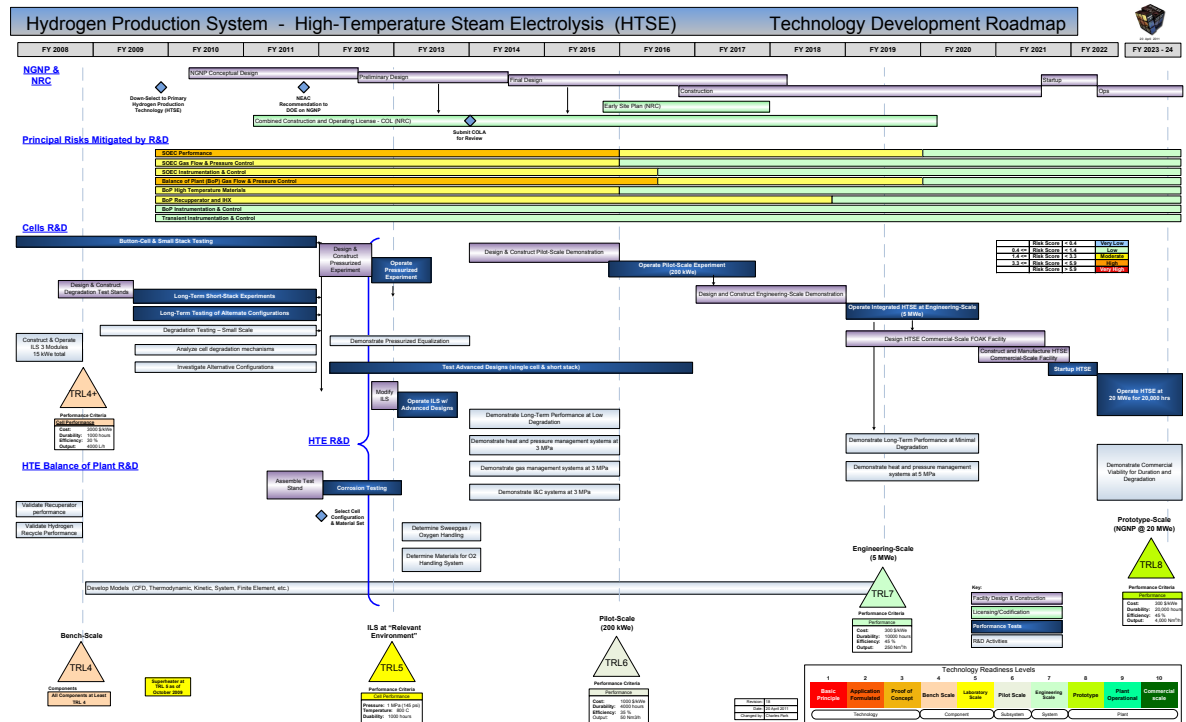


# ***SE Applications for Successful HTSE***

- Rigorous, transparent down-selection of H<sub>2</sub> production technologies
- *HTSE Flowsheets* integrated with industrial process applications
- Relational Risk Management process to focus development
- Developed detailed Test Plans for methodical testing
  - 8 components advancing through 4 maturity levels

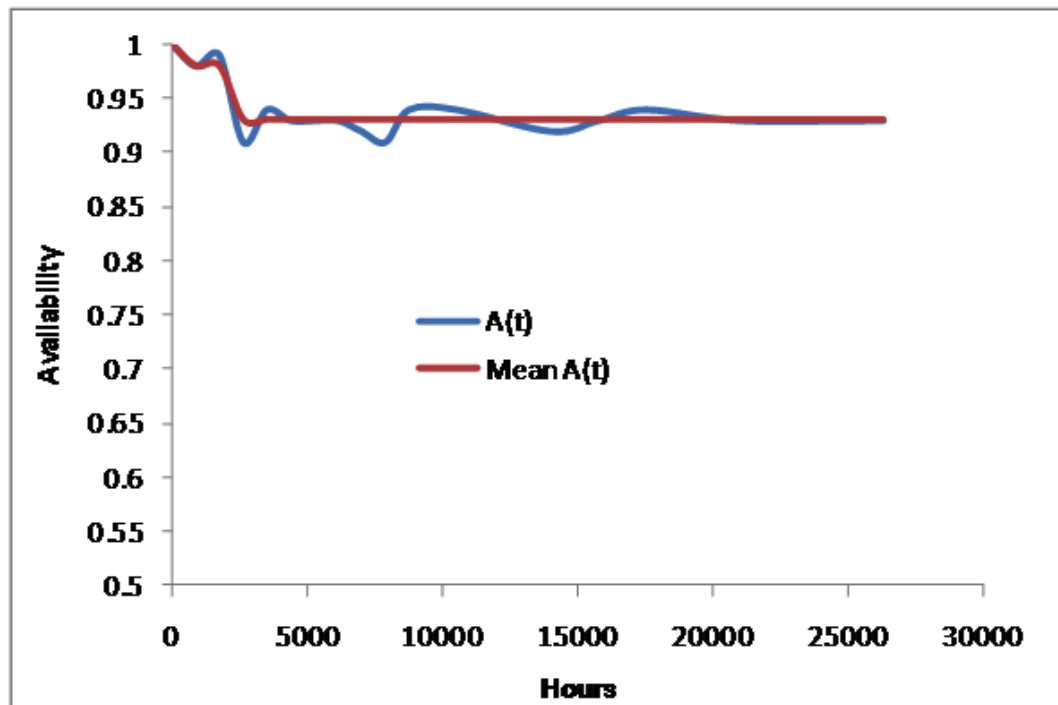
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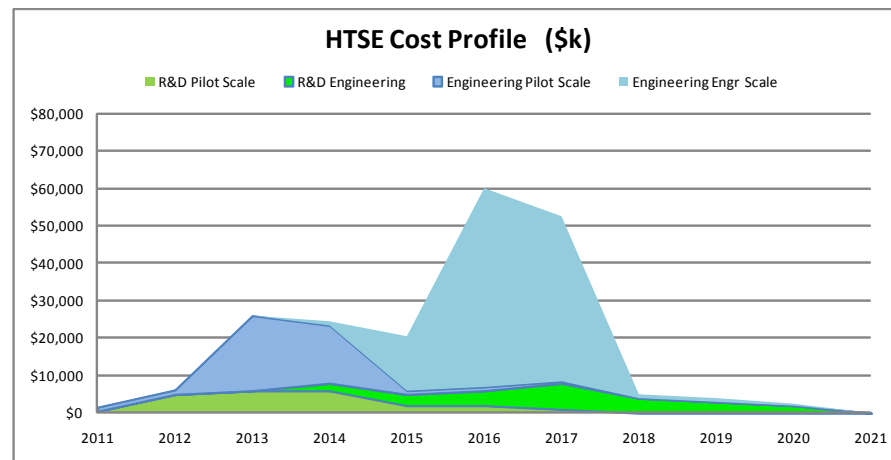
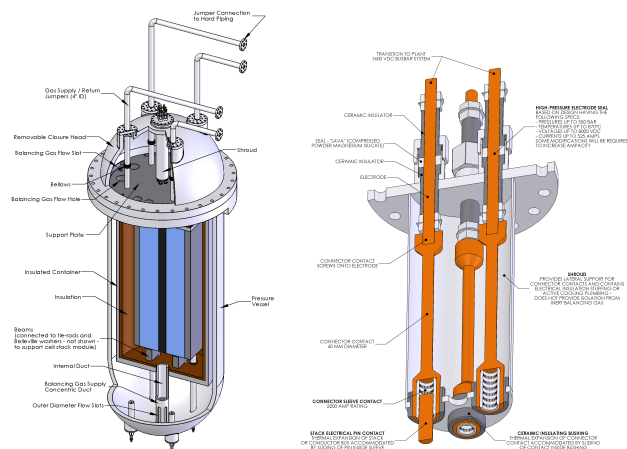
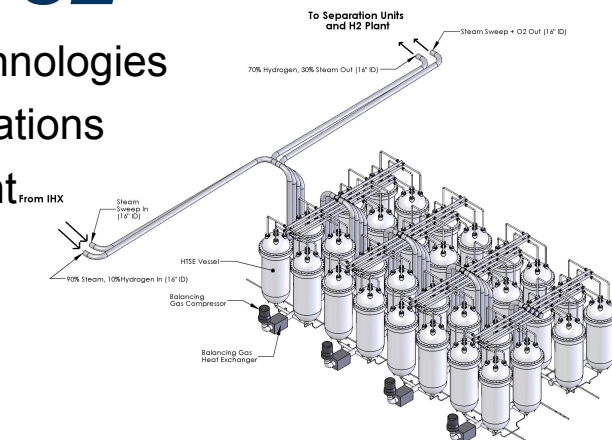
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**R&D**  
R&D Pilot Scale  
R&D Engineering

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
R&D Pilot Scale	500	5000	6000	6000	2000	2000	1000					22500
R&D Engineering				2000	3000	4000	7000	4000	3000	2000		25000
<b>Total</b>	<b>500</b>	<b>5000</b>	<b>6000</b>	<b>8000</b>	<b>5000</b>	<b>6000</b>	<b>8000</b>	<b>4000</b>	<b>3000</b>	<b>2000</b>		<b>47500</b>
<b>Engineering</b>												
Engineering Pilot Scale	1100	1200	20000	15400	1000	1000	500	0				40200
Engineering Engr Scale				1100	14500	53000	44000	1000	1000	500		115100
<b>Total</b>	<b>1100</b>	<b>1200</b>	<b>20000</b>	<b>16500</b>	<b>15500</b>	<b>54000</b>	<b>44500</b>	<b>1000</b>	<b>1000</b>	<b>500</b>		<b>155300</b>
<b>Total</b>												<b>202800</b>

# ***SE Applications for Successful HTSE***

- Rigorous, transparent down-selection of H<sub>2</sub> production technologies
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- Relational Risk Management process to focus development
- Developed detailed Test Plans for methodical testing
- Technology Development Roadmap developed
- Preliminary RAMI Analysis to guide design
- Life-cycle cost estimates completed
- Requirements Management

## **Summary:**

- NGNP / HTSE Project involved significant SE
- SE was implemented in the early stages of the project
- Used innovative SE tools and methods as needed

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