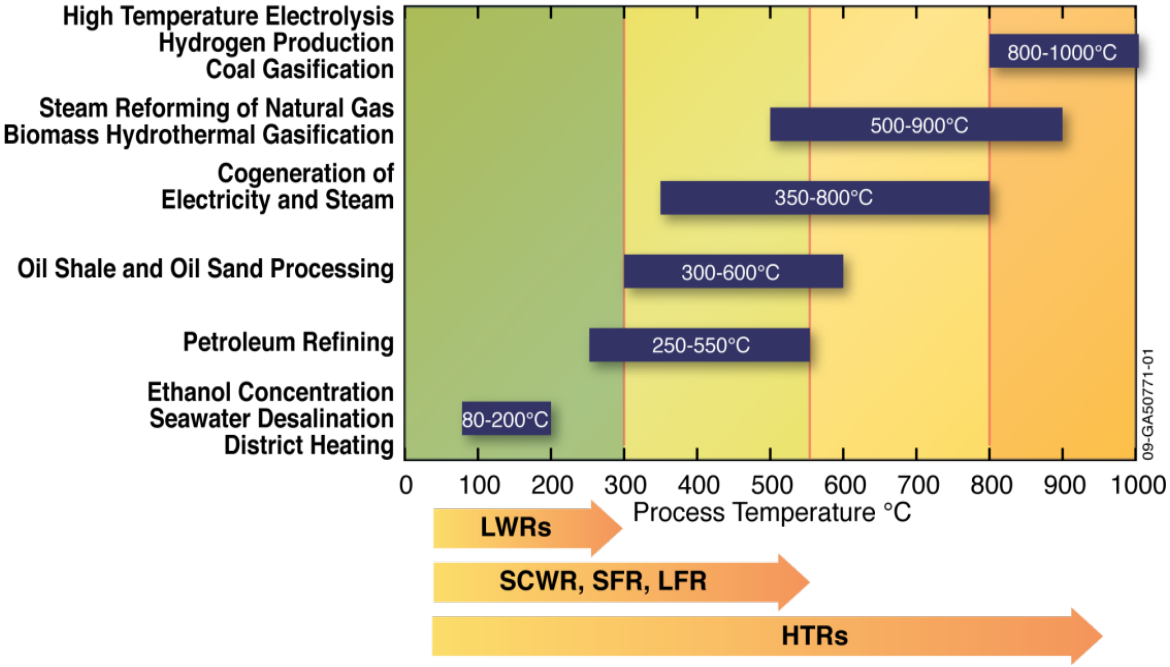
Purpose

- Select the "best" Hydrogen Technology for deployment

Background

- Energy Policy Act 2005 authorized NGNP with hydrogen production
- Gas-cooled (helium) nuclear reactor
- Graphite moderated
- 600 MW_{th} per unit
- 7 MPa
- 750 to 800 °C
- 60-year design life



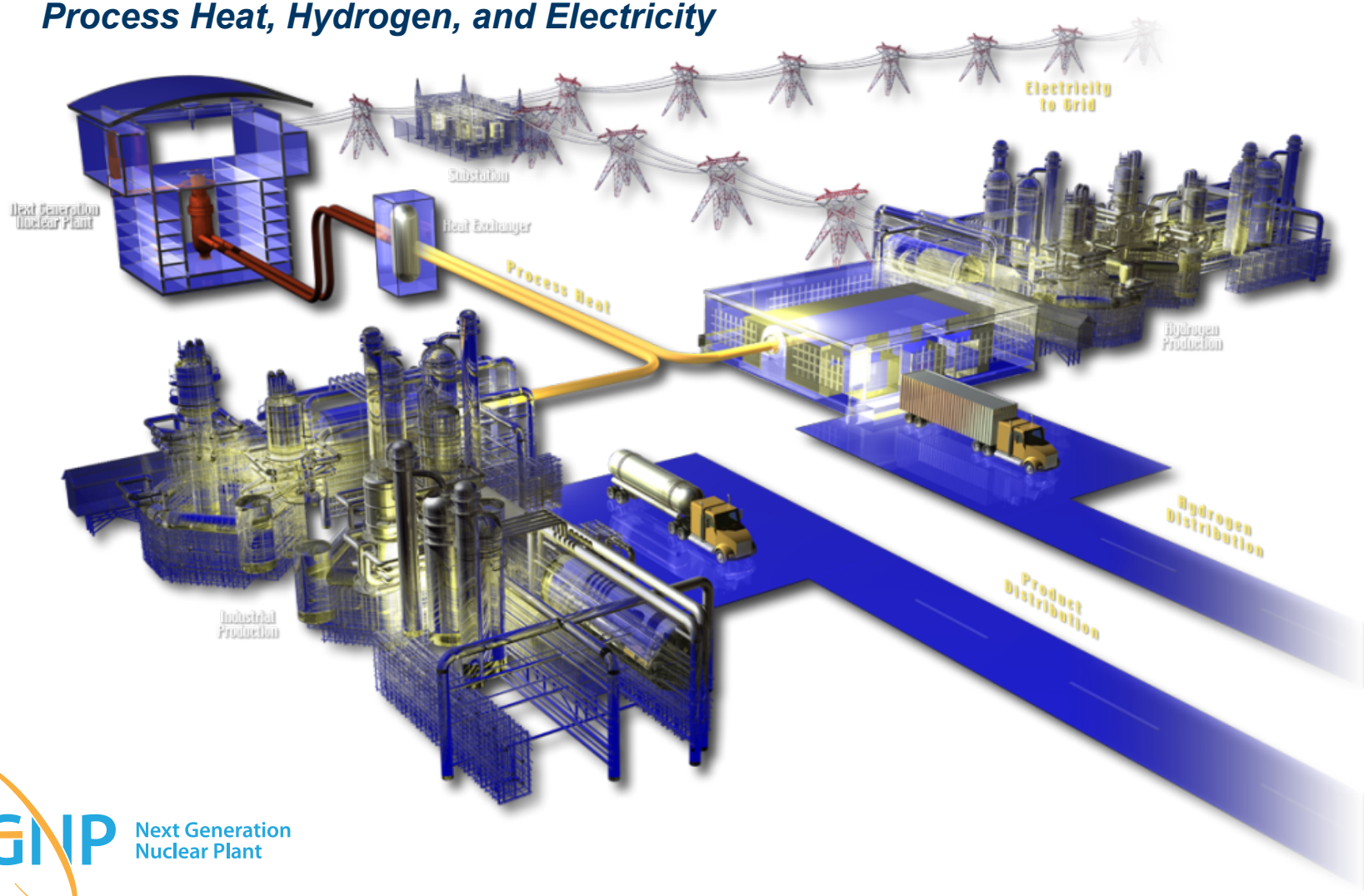
NGNP Next Generation Nuclear Plant

Hydrogen Production and Consumption

- Current Hydrogen Production
  - Methane Steam Reforming
  - Conventional Electrolysis
- Current Hydrogen Consumption - 42 Million Tons per year (World-wide)
  - Ammonia Production – 60%
  - Petroleum Refining – 23%
  - Methanol Manufacture - 9%
  - Chemical, Metallurgical Uses – 8%
- Nuclear Hydrogen Production
  - DOE Nuclear Hydrogen Initiative started in 2003
  - A May 2008 report showed that $140M could be saved by near-term down-selection
  - INL planned and organized the down-selection in 2009

Next Generation Nuclear Plant

Process Heat, Hydrogen, and Electricity



NGNP Next Generation Nuclear Plant

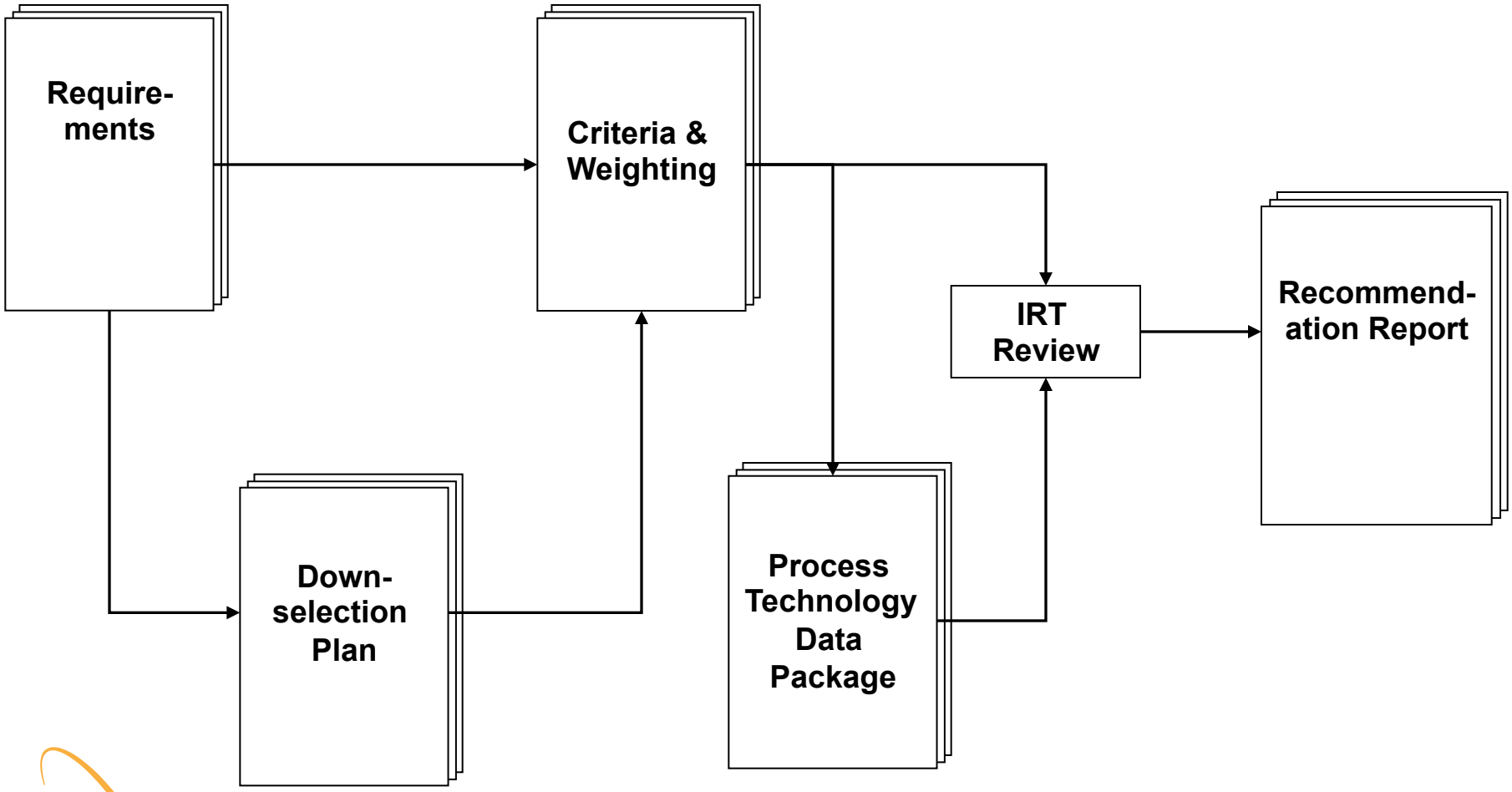
Objective

- Reduce cost of development by focusing on one technology
- Review current technologies to verify that the Department of Energy's (DOE) previous selection of the most advanced processes was valid:
  - Sulfur-Iodine
  - High-Temperature Steam Electrolysis (HTSE)
  - Hybrid Sulfur

Requirements

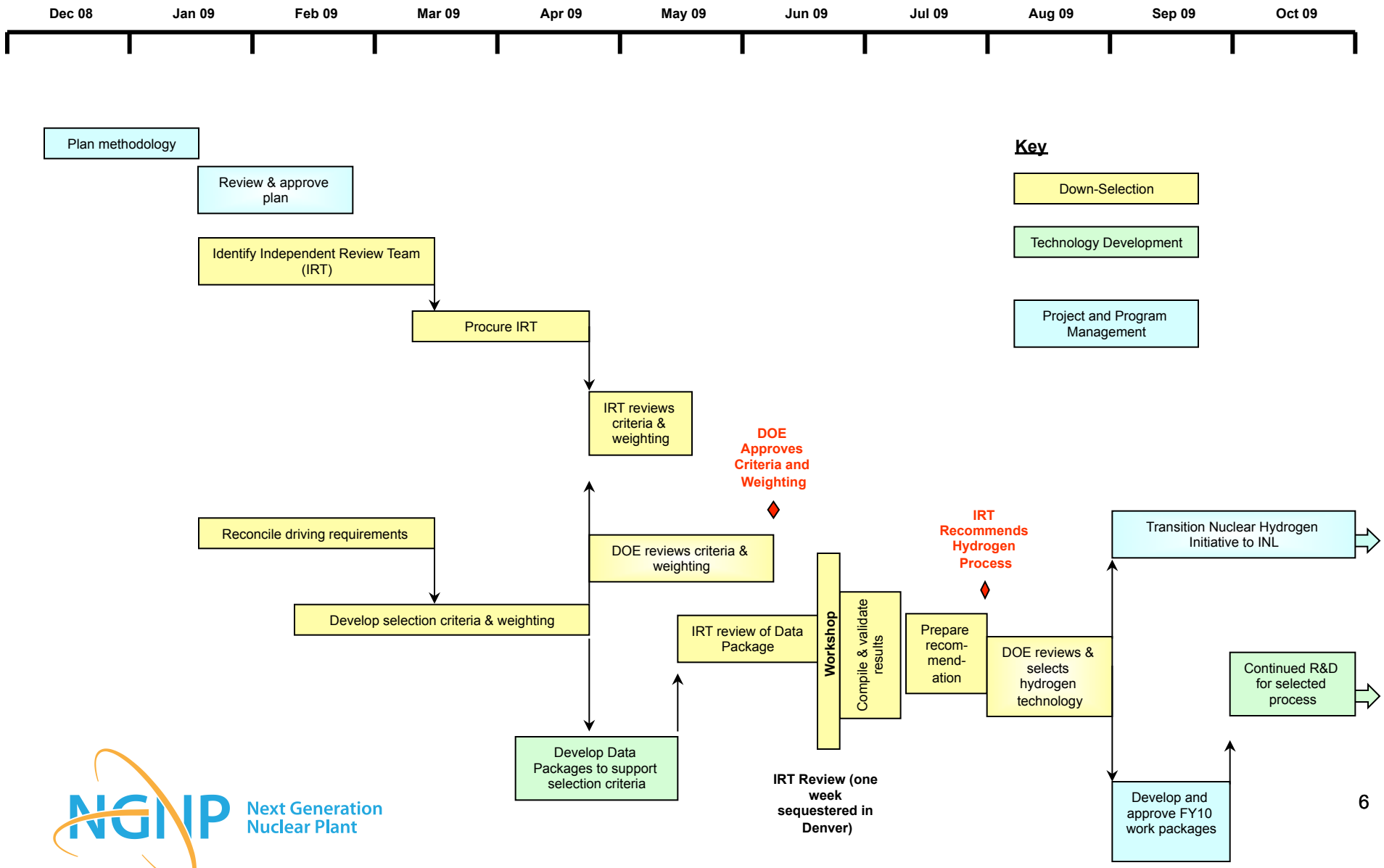
- Able to be developed for deployment by 2021
- Utilize up to 50 MW_{th} of high-temperature heat at 700°C
- Extreme objectivity required to justify re-directing R&D funds and terminating some projects

Methodology

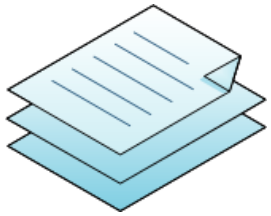


NGNP Next Generation Nuclear Plant

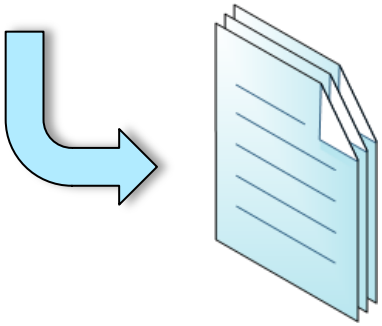
Schedule


Dec 08
Jan 09
Feb 09
Mar 09
Apr 09
May 09
Jun 09
Jul 09
Aug 09
Sep 09
Oct 09
Plan methodology
Review & approve plan
Identify Independent Review Team (IRT)
Procure IRT
IRT reviews criteria & weighting
DOE Approves Criteria and Weighting
Reconcile driving requirements
DOE reviews criteria & weighting
Develop selection criteria & weighting
IRT review of Data Package
Workshop
Compile & validate results
IRT Recommends Hydrogen Process
Prepare recom-mend-ation
DOE reviews & selects hydrogen technology
Transition Nuclear Hydrogen Initiative to INL
Continued R&D for selected process
Develop Data Packages to support selection criteria
IRT Review (one week sequestered in Denver)
Develop and approve FY10 work packages
Key
Down-Selection
Technology Development
Project and Program Management

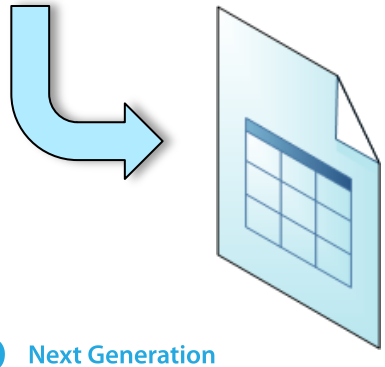
Selection of Discrimination Criteria



Searched industry, academia and governmental references for candidate criteria related to Hydrogen Production



Created a "Criteria Summary" for each reference
- Author, title, date, source, affiliation, etc.
- Compiled criteria list with definitions



Developed spread sheet showing criteria and frequency per reference
- Identified most frequent usage
- Allowed combination of similar criteria
- Allowed elimination of less relevant criteria
- Provided defensible basis for candidate criteria

Systematic Tally of Criteria Citations

Criteria and Constraints from Select NGNP / NHI Documents

Criteria	NGNP TDRM	Westinghouse HPS Report	Technology Neutral Report	NRC Review of DOE-NE	INEEL/EXT-03-01163	INEEL/EXT-04-01816	INL/EXT-08-14395	INL/EXT-08-14370	INL/EXT-07-12999	H2,FC & Infrastructure	Non-Nuclear, H2 Production	Library Search	H2 Demo Project Report	Internet Search	Total	Comments
Process Robustness (RAMI)	1		1	1	1				1		1	1		1	7	Availability during Operations
Life cycle and life cycle cost	1		1						1		1	1	1	1	6	Cost of Hydrogen
Contamination Control			1		1		1	1		1		1			6	Purity of Hydrogen
Efficiency	1		1						1		1		1	1	5	Cost of Hydrogen
Reactor core outlet temperature		1			1		1		1			1			5	Key Assumptions and Constraints
H2 Purity Level					1	1				1	1	1			5	Purity of Hydrogen
Waste			1						1			1	1	1	5	Waste Management
Scalability	1		1									1	1	1	4	Availability during Operations
Occupational Safety	1					1			1		1			1	4	Key Assumptions and Constraints
H2 Storage and Distribution					1				1			1	1		4	Criteria considered but not used
Material Availability	1		1										1	1	3	Cost of Hydrogen
Cost of Hydrogen	1	1		1	1										3	Cost of Hydrogen
H2 Production and/or in peak elec times	1								1		1		1		3	Quantity of Hydrogen Produced
By-products generated		1										1		1	3	Availability during Operations
Start up and shut down				1								1	1		3	Availability during Operations
H2 Safety / Licensing				1	1	1									3	Key Assumptions and Constraints
Technical Maturity		1	1											1	3	Technology Maturity
Environmental impacts	1		1											1	2	Key Assumptions and Constraints
Operating Risk		1				1									2	Availability during Operations
System Complexity		1										1			2	Availability during Operations
Manufacturability			1								1				2	Cost of Hydrogen
Power input required		1										1			2	Cost of Hydrogen
Development Schedule		1		1											2	Development Impact
Technology Risk		1						1							2	Development Risk
Operating pressure		1											1		2	Flexibility to serve Various Applications
Corrosion Resistance	1	1													1	Criteria considered but not used
Ability to vary process outputs												1			1	Availability during Operations
Capital Cost		1													1	Cost of Hydrogen
R&D Cost		1													1	Development Impact
Major Technology Challenges		1													1	Technology Maturity
Total	10	14	10	5	7	4	2	2	8	2	7	13	9	10		

Nine Criteria Were Selected

Performance (35%)
- 3.1 Quantity of Hydrogen
- 3.2 Purity of Hydrogen
- 3.3 Serve Various Applications
- 3.4 Waste Management

Cost (30%)
- 3.5 Cost of Production
- 3.6 Cost Uncertainty
- 3.7 Development Cost

Risk(35%)
- 3.8 Technical Maturity
- 3.9 Development Risk

Used "Quick-Compare" (modified Excel on steroids) to perform computations

An Expert Independent Review Team

Industry and Academia

International

Aggressive & Knowledgeable

Thorough

Worked well together

Bob Varrin – Lead, Dominion Engineering

David Scott, University of Victoria BC

Ken Reifsneider, University of South Carolina

Patricia Irving, InnovaTek & University of Washington

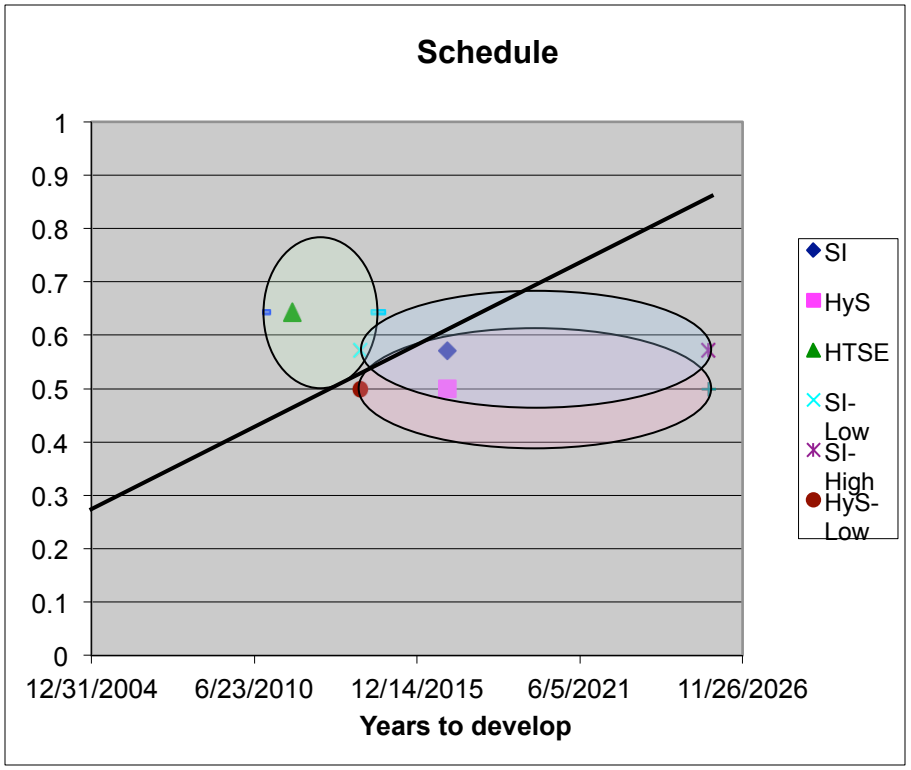
Greg Rolfson, Entergy

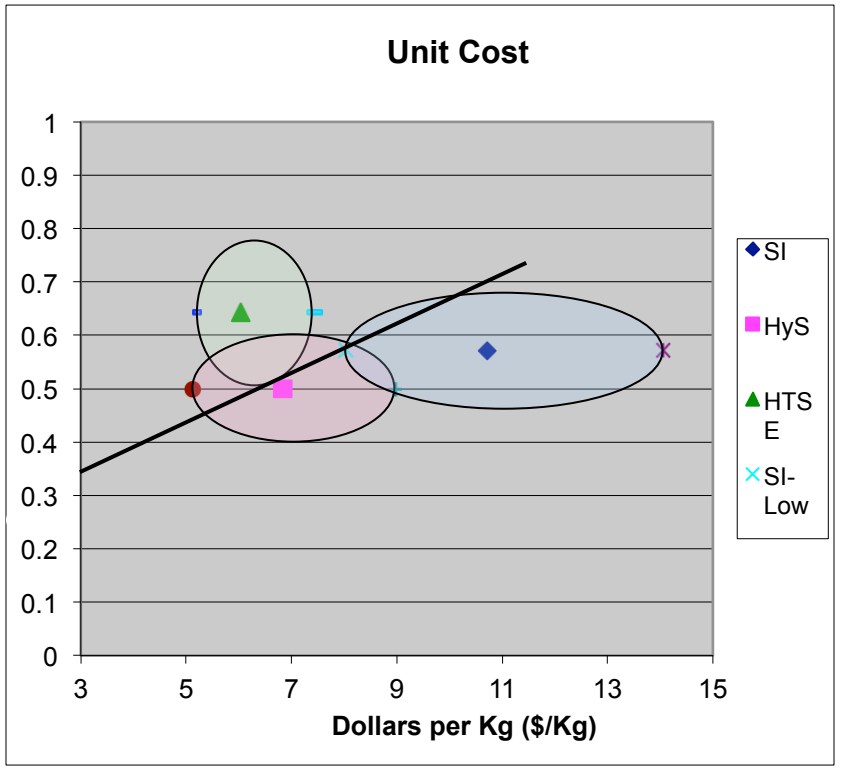
Scoring Results

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_2 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%)	Technical Maturity (TRLs)	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%	Insur-mountable	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	

NGNP Next Generation Nuclear Plant

Options Analysis amid Uncertainty



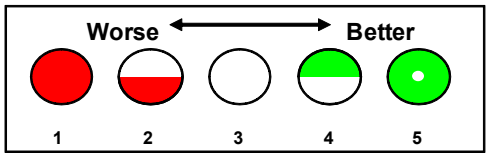


NGNP Next Generation Nuclear Plant

A Quick Comparison

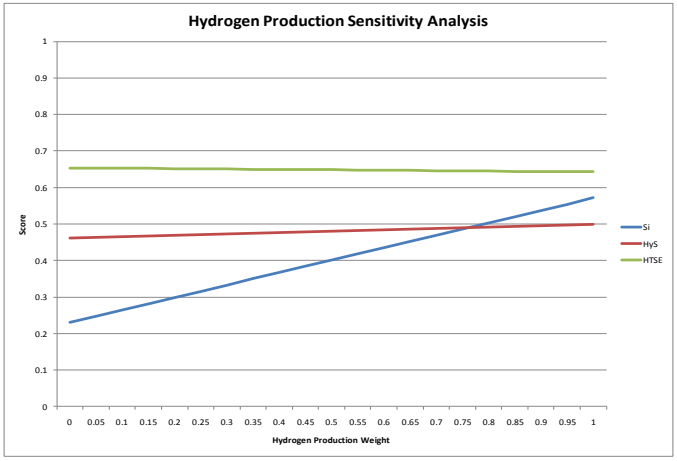
Problem Trying to Solve:	Identify the most effective Hydrogen Production System approach to creating hydrogen in an effective, efficient, high quality, low cost manner with in a reasonable time.
Scoring Method:	1 to 5 Scale

Goals / Criteria	Alternatives: Si Overall Score: 35%	HyS Overall Score: 47.5%	HTSE Overall Score: 65%
Hydrogen Production - 35%			
Quantity of Hydrogen Produced	3.0	3.0	3.0
Purity of Hydrogen	3.0	3.0	4.0
Availability During Operations	5.0	3.0	2.0
Flexibility to Serve Various Applications	3.0	3.0	5.0
Waste Management	3.0	3.0	3.0
Cost - 30%			
H2A Model Results	2.0	3.0	4.0
Validity of H2A Assumptions	3.0	3.0	3.0
Development Cost	2.0	3.0	4.0
Risk - 35%			
Technical Maturity - Current	2.0	2.0	4.0
Development Risk	1.0	3.0	3.0
Development Schedule	2.0	3.0	4.0

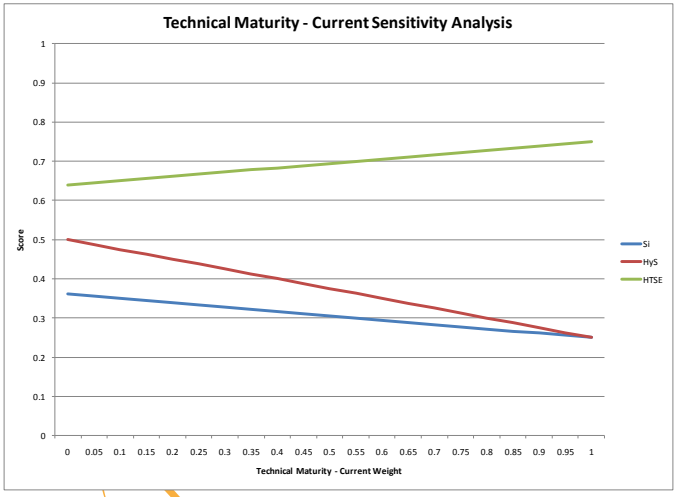


Sensitivity Analysis

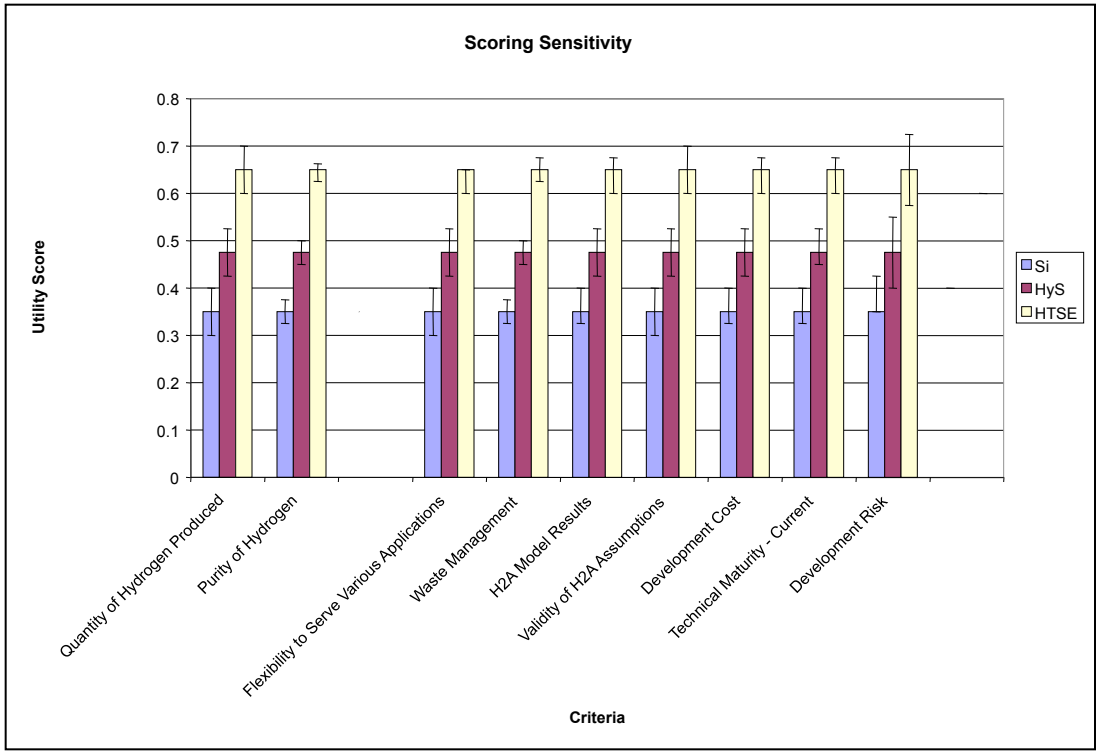
Goal Weight Sensitivity Analysis



Criteria Weight Sensitivity Analysis



Results were not sensitive to expected variation



IRT Recommendations

- Focus on HTSE:
  - Highest probability of meeting down-selection criteria
  - Most efficient production of hydrogen at NGNP conditions

Summary

- Systems Engineering for NGNP
  - Systems Requirements Manual
  - Technology Readiness Assessment
  - Technology Readiness Level Baseline
  - Technology Development Roadmaps
  - Risk Management System (Model)
  - Risk Register
  - Downselection

"NGNP has enhanced typical risk management approaches for high-technology projects … acknowledge in this deliverable the significant quality enhancements in risk management that NGNP has made … This alone is project management best practice … This approach, combined with the technology development roadmap effort, …highlighted …as some of the best work seen in this area of expertise."

Documented by the DOE Customer