Hydrogen Generation and Industrial Heat Opportunities for Nuclear Plants in the Gulf Coast Region

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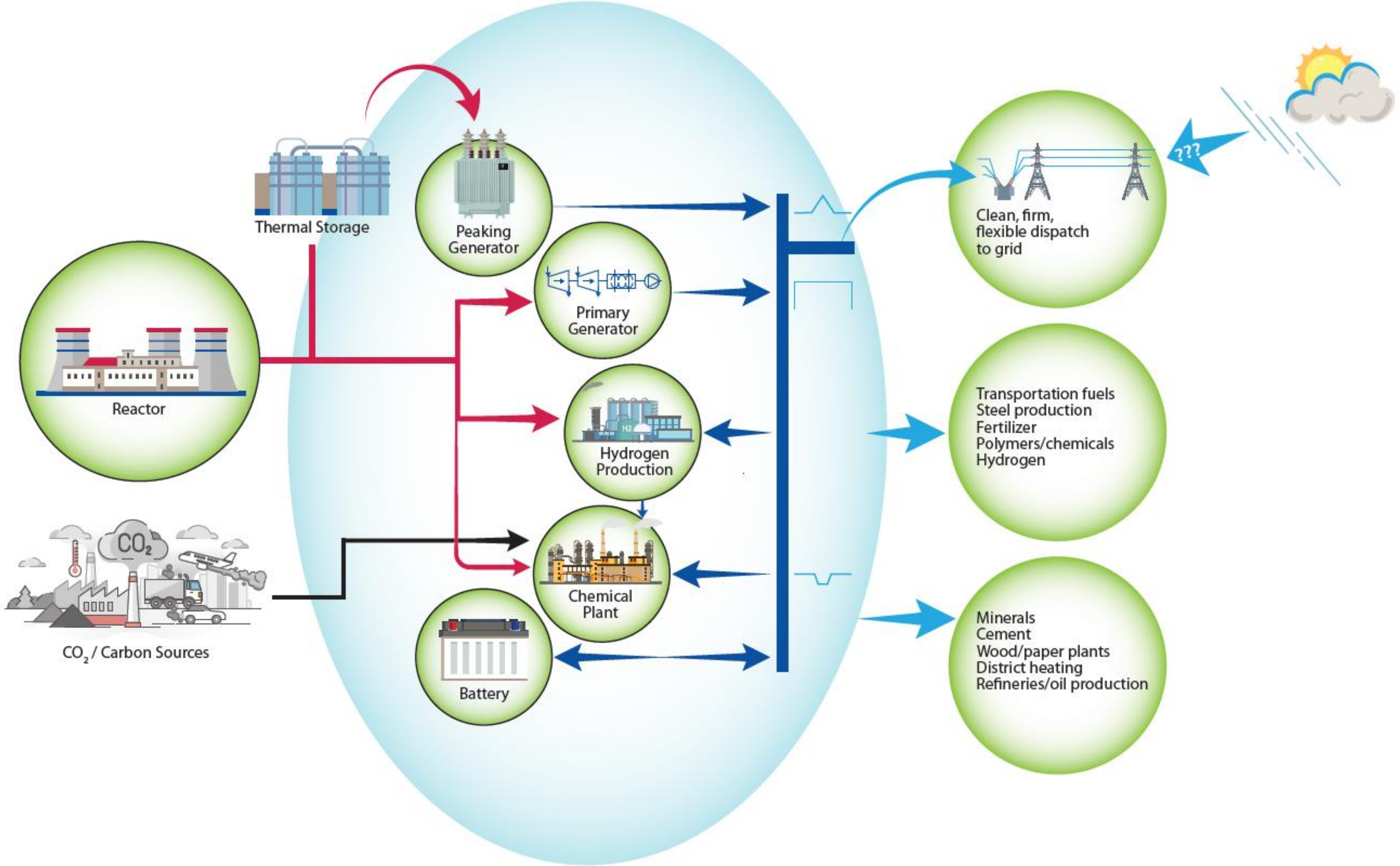
3/6/2025

Background

- Nuclear energy can be a continuous source of thermal and electrical energy with near-zero emissions.
- Using the existing light water reactor (LWR) power stations, there are potential opportunities for coupling nuclear plants with hydrogen production and heat delivery.



[1] Knighton, L et al (2021) Techno-Economic Analysis of Product Diversification Options for Sustainability of the Monticello and Prairie Island Nuclear Power Plants. https://doi.org/10.2172/1843030
[2] Wendt, D et al (2022) High Temperature Steam Electrolysis Process Performance and Cost Estimates. https://doi.org/10.2172/1867883
[3] Westover, T et al (2023) Preconceptual Designs of Coupled Power Delivery between a 4-Loop PWR and 100–500 MWe HTSE Plants.
[4] Diaz, M et al (2024) Hydrogen Generation and Industrial Heat Opportunities for Nuclear Plants in the Gulf Coast, INL/RPT-24-80189, https://doi.org/10.2172/2439929

Objectives and Goals~FY24 and FY25

Nuclear integration with hydrogen opportunities to provide heat and power to existing industry via existing infrastructure

H_2 Market Assessment

- H_2 and Heat market opportunities around Light Water Reactors in the Gulf Coast Region.

Business Case Assessment

- Opportunities to produce and **distribute hydrogen (via HTSE and LTE) and heat** at Gulf Coast NPPs to local industry.
- Inclusion of options, pipelines, and PTC credit.

Goals

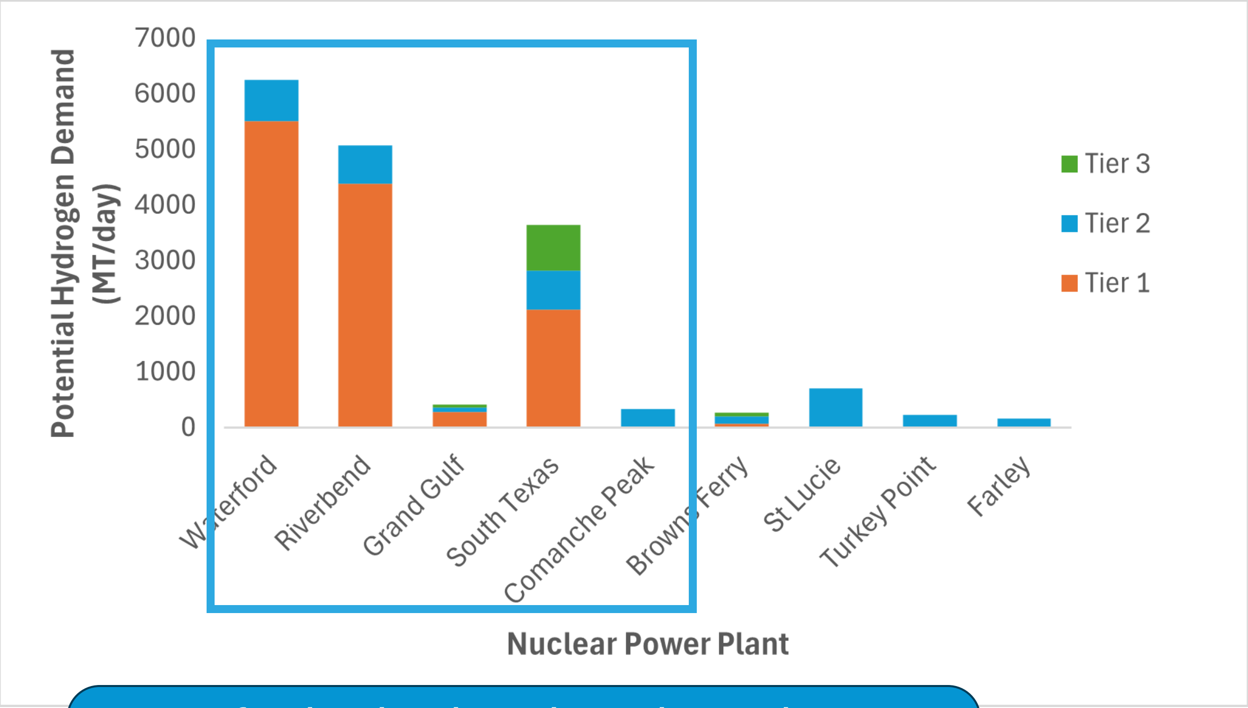
- FY24: Steady State TEA for Hydrogen Production
- FY25: Steady State and Dynamic TEA for Heat delivery, against H_2 and Electricity Generation.

Case Study Selection

Light Water Reactor in Gulf Coast Region

NPPs in Gulf Coast	Thermal Capacity (MW-th)	Plant design Electricity Capacity (MWe-ac)	Thermal Efficiency	Capacity Factor (As of 2022)
Browns Ferry 1	3458	1200	34.70%	90.0%
Browns Ferry 2	3458	1200	34.70%	100.0%
Browns Ferry 3	3458	1210	34.99%	87.3%
Comanche Peak 1	3612	1205	33.36%	88.7%
Comanche Peak 2	3612	1195	33.08%	100.0%
Farley 1	2775	874	31.50%	72.7%
Farley 2	2775	883	31.82%	93.6%
Grand Gulf 1	4408	1401	31.78%	73.1%
River Bend 1	3091	967	31.28%	100.0%
Saint Lucie 1	3020	981	32.48%	91.3%
Saint Lucie 2	3020	987	32.68%	96.2%
South Texas 1	3853	1280	33.22%	100.0%
South Texas 2	3853	1280	33.22%	90.8%
Turkey Point 3	2644	837	31.66%	100.0%
Turkey Point 4	2644	821	31.05%	91.3%
Waterford 3	3716	1168	31.43%	77.4%

H_2 demand close to the LWR in the Gulf Coast



Waterford, Riverbend, and South Texas LWR NPPs have the highest nearby H2 existing demand

Potential Hydrogen Demand

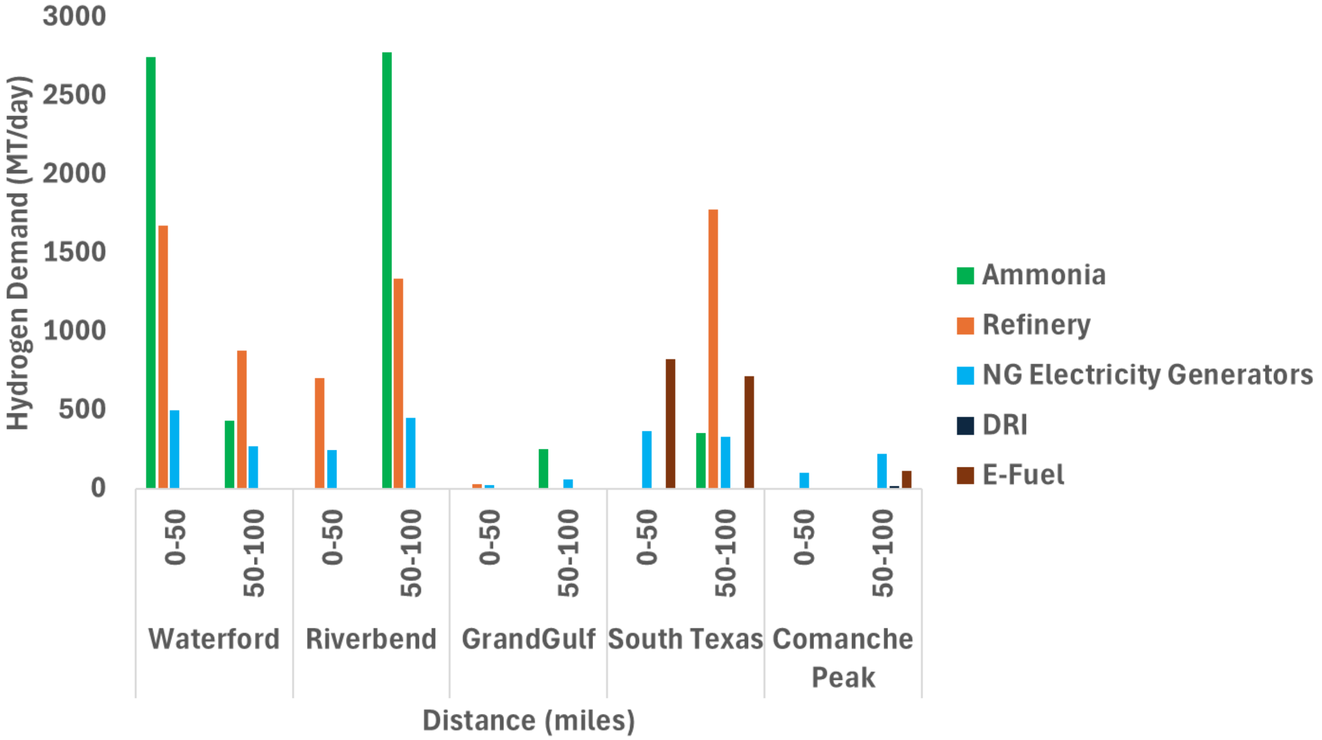
Existing facilities using hydrogen:

- Petroleum refineries
- Ammonia and fertilizer production

Future demand:

- Natural Gas (NG) blending with hydrogen for NG electricity generators
- Direct-reduced iron for metals
- Fuel Cell Electric Vehicles

Waterford, Riverbend, and South Texas LWR NPPs have the highest nearby H2 existing demand

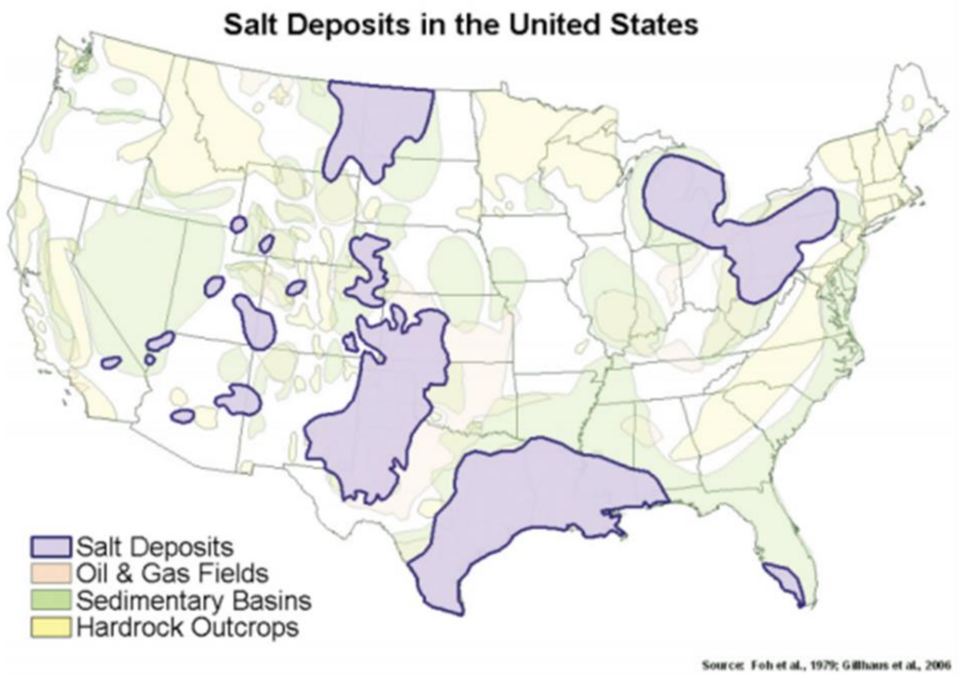


Case Study Selection~ Hydrogen Opportunities

US Gulf Coast Hydrogen Pipelines in 2020

Congressional Research Service. (March 2, 2021). Pipeline Transportation of Hydrogen: Regulation, Research, and Policy. https://crsreports.congress.gov/product/pdf/R/R46700)

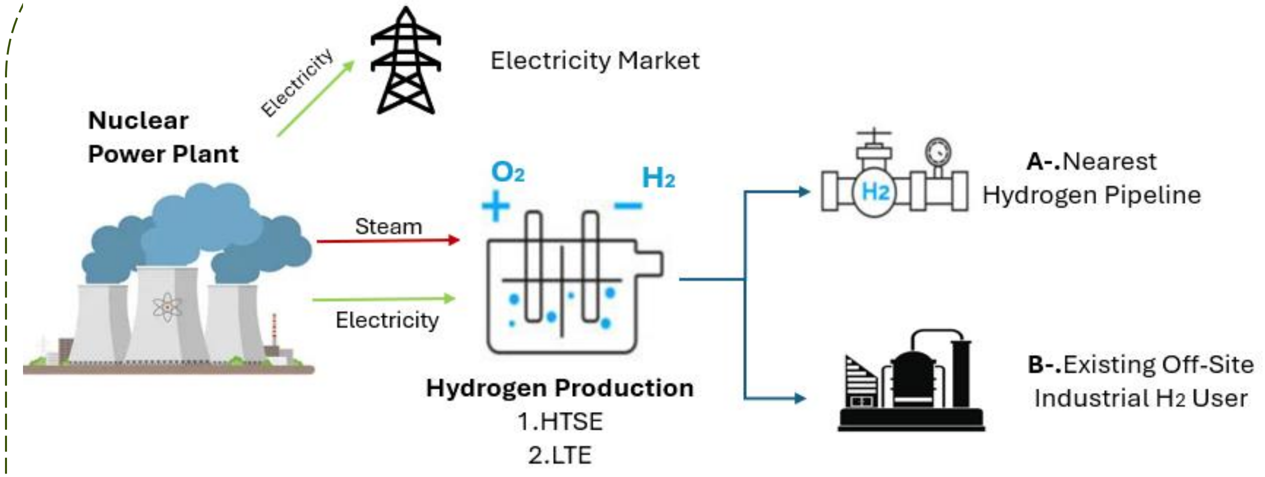
Potential U.S Geologic Storage



Praxair/Linde and Sandia National Laboratory

H_2 Production Analysis

Process



Nuclear Integrated hydrogen production cases	Deliver Hydrogen to nearby hydrogen-pipeline network	Deliver Hydrogen to nearby industrial users
HTSE (Produce maximum 351 tons/day of H_2)	Case 1A	Case 1B
LTE (Produce maximum 231 tons/day of H_2)	Case 2A	Case 2B

TEA

NIHPA Tool

Outputs

- -LCOH
- -H_2 production rate
- -IRR
- -NPV_{H2}
- - NPV_{BAU*}
- -Sensitivity Analysis
- -Preference Analysis
- -Competitive Analysis

*BAU: Business as Usual

Hydrogen delivery from selected NPPs

Closest and largest H2 demand is near Waterford and Riverbend

NPP	Name	Demand Type	Market Demand (MT/day)	Max H2 Supply (MT/day)	Dist. (mi)	Pipeline Delivery costs from HDSAM ($/kg)
Waterford	HTSE to Nearby Pipeline	Pipeline	351	351	0.2	$0.09
	LTE to Nearby Pipeline	Pipeline	231	231	0.2	$0.09
	HTSE to Dyno Nobel (Ammonia)	Current	400	351	15.5	$0.10
	LTE to Dyno Nobel (Ammonia)	Current	400	231	15.5	$0.10
Riverbend	HTSE to Nearby Pipeline	Pipeline	351	351	19.9	$0.10
	LTE to Nearby Pipeline	Pipeline	351	231	19.9	$0.11
	HTSE to Exxon Mobil Corp (Refinery)	Current	535	351	24.7	$0.10
	LTE to Exxon Mobil Corp (Refinery)	Current	535	231	24.7	$0.11
Grand Gulf	HTSE to Nearby Pipeline	Pipeline	351	351	105.4	$0.19
	LTE to Nearby Pipeline	Pipeline	351	231	105.4	$0.22
	HTSE to Ergon Inc (Refinery)	Current	28.2	28.2	19.6	$0.24
	LTE to Ergon Inc (Refinery)	Current	28.2	28.2	19.6	$0.24
STP	HTSE to Nearby Pipeline	Pipeline	351	351	25.2	$0.10
	LTE to Nearby Pipeline	Pipeline	231	231	25.2	$0.11
	HTSE to HIF Global (Methanol)	Future	600	351	2	$0.09
	LTE to HIF Global (Methanol)	Future	600	231	2	$0.09
CP	HTSE to Nearby Pipeline	Pipeline	351	351	267.8	$0.37
	LTE to Nearby Pipeline	Pipeline	231	231	267.8	$0.48
	HTSE to Hereford Renewable (E-fuels)	Future	110	110	98.6	$0.29
	LTE to Hereford Renewable (E-fuels)	Future	110	110	98.6	$0.29

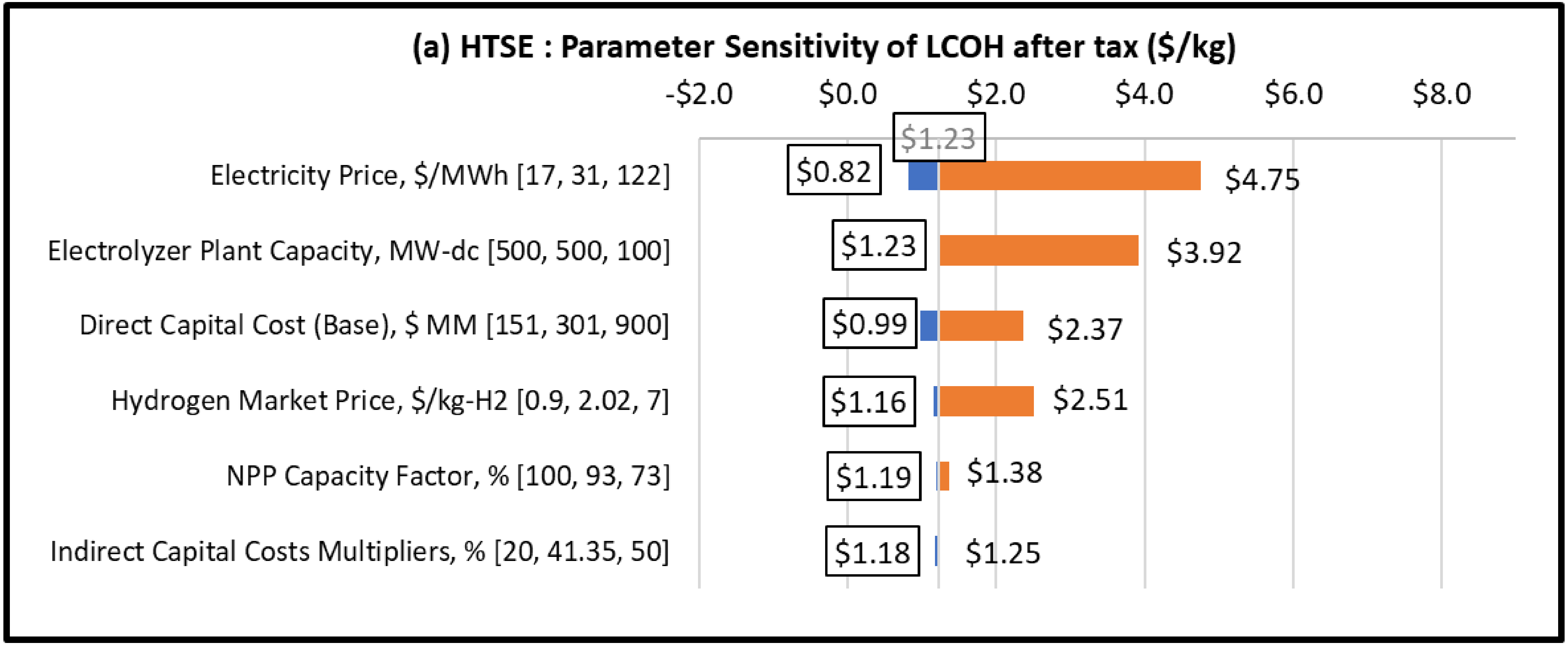
Sample of Financial performance for producing H2, without and with 45V tax credits

		South Texas NPP Example	
	Case	Without 45V	With 45V
LCOH+COD ($/kg-$H_2$)	HTSE-pipeline	$2.02	$1.33
	HTSE-industry	$2.01	$1.32
	LTE-pipeline	$3.06	$2.42
	LTE-industry	$3.04	$2.39

*LCOH: Levelized cost of Hydrogen
*COD: Cost of Delivery

Assumes 500 MWe design for H_2 plant but only 200 MWe qualifies for 45V Tax credits.

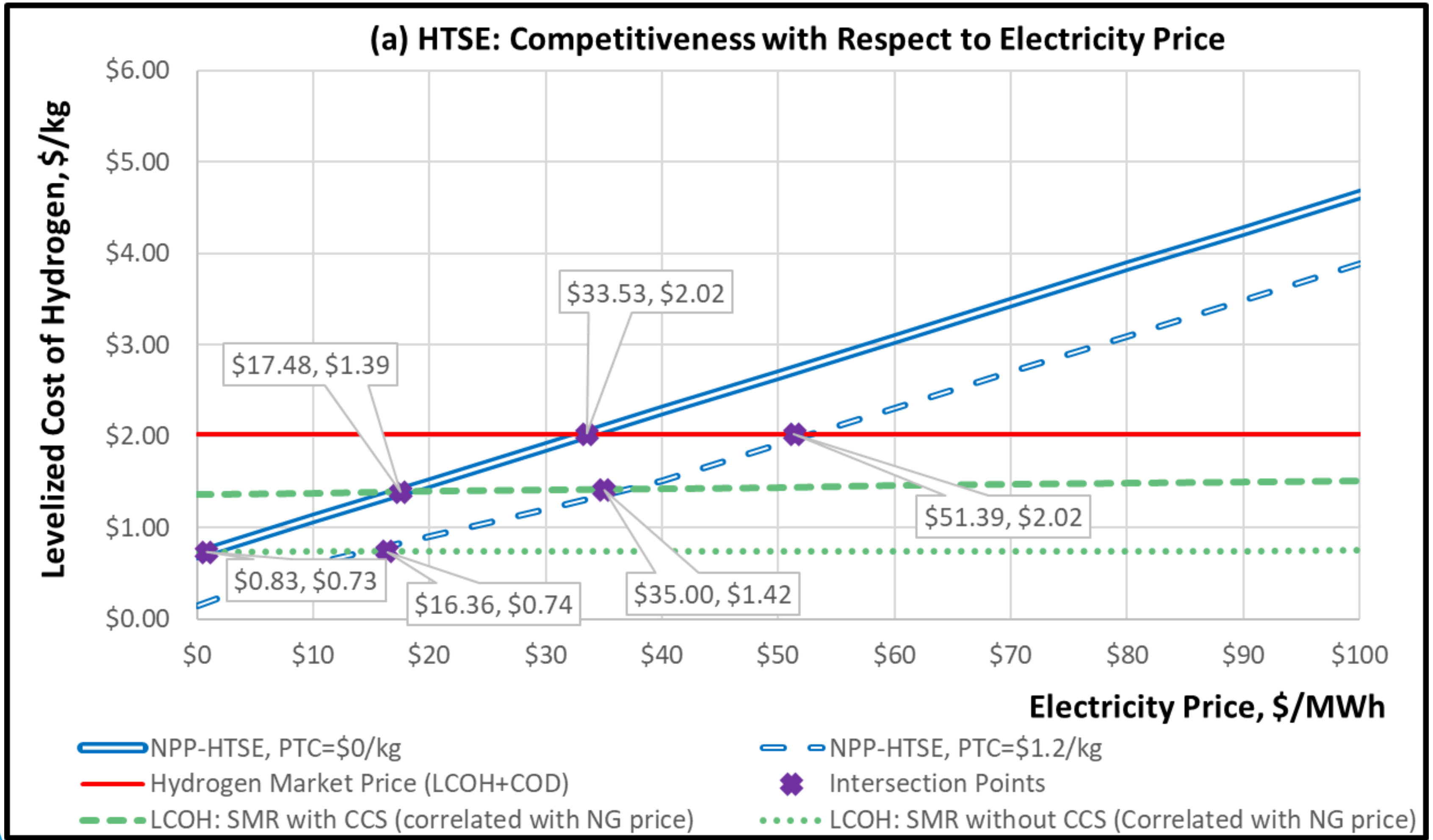
General Sensitivity Analysis (LCOH after taxes)



Shows the sensitivity to different assumptions. Electricity price and Electrolyzer Cost and Capacity are the largest factors in Hydrogen LCOH

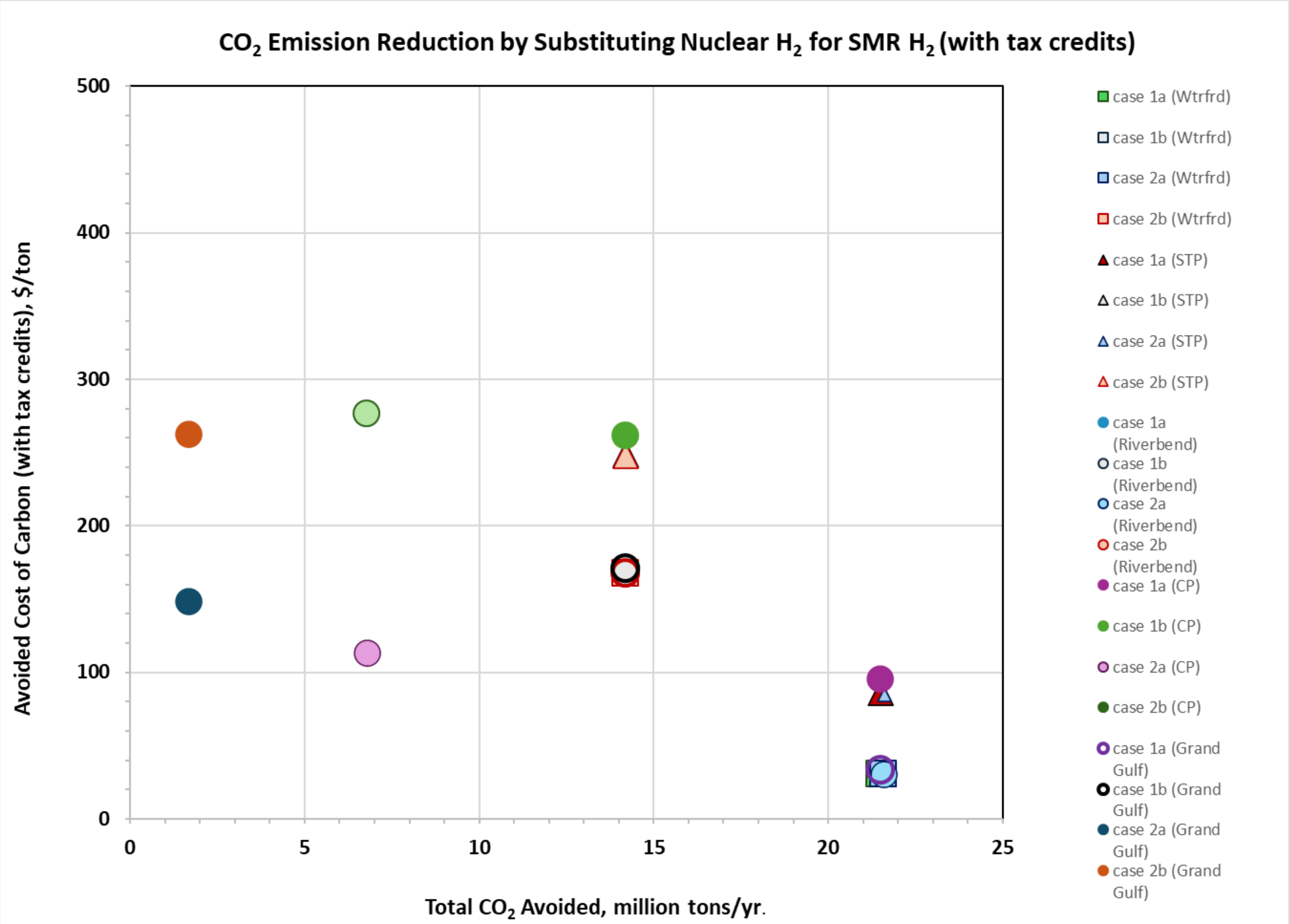
Comparisons with blue Hydrogen (LCOHs vs. elec price)

For example, for NPP-HTSE and H_2 sale price of $2/kg-H2:
-W/ PTC, LCOH would be $1.42 @ 35 $/MWh electricity price



*Because design was already done for 500 MWe when clarification on 45V came out—to pseudo adjust to 200 MWe at $3/kg-H2, the calculation here was re-run at $1.2/kg-H2 PTC

Avoided Cost of Carbon for Total CO_2 Avoided



Simple version of this chart to be incorporated afternoon 3/10

LWRS
LIGHT WATER REACTOR SUSTAINABILITY

Conclusions~FY24

- The Gulf Coast region, with its extensive hydrogen pipeline infrastructure, could integrate H_2 production with LWRs.
- Key findings highlight the highest hydrogen demand surrounding Waterford, Riverbend, and South Texas NPPs, with ammonia and refineries being predominant consumers.
- HTSE scenarios (Case 1A and 1B) have lower LCOHs than LTE scenarios (Case 2A and 2B) due to higher hydrogen production rates.
- LCOHs for Grand Gulf and Comanche Peak due to reduced hydrogen demand in close proximity to the plants.

LWRS
LIGHT WATER
REACTOR
SUSTAINABILITY

Sustaining National Nuclear Assets

lwrs.inl.gov

Study assumptions for Technoeconomic Analysis

Parameters used for TEA	Values	Assumptions
Start-up year of the hydrogen production	2030	It is assumed that the timing of study analysis window for hydrogen adoption is within 5 years.
Electrolyzer plant lifespan	20 years	Specific lifetime specified consistent with INL previous studies
Hydrogen market type	Regulated	NPPs are simplistically evaluated as merchant entities to avoid the complexities of a regulated utility framework.
Maximum electrolyzer capacity	500 MW-dc	Integration of steam extraction and electrical take-off modifications will be appropriately licensed under NRC rules without a license amendment to a maximum 500 MW-direct current of the electricity from NPP
Tax Credits: IRA 45V	\$3/kg-H2	hydrogen tax credit of \$3/kg-H2 for 10 years (2030–2039)
Tax Credits: IRA 45U	Gross receipt dependent	Nuclear clean-electricity tax credits from January of 2030 to December of 2032
Total installed direct capital cost (DCC)	\$397 million (in 2021 dollars)	The contingency is included for all sizes of the HTSE plants
Additional integration costs including mechanical interface and switchyard for HTSE	\$64 million	The total DCC is calculated by adding the installed DCC and the additional integration costs for HTSE
Additional integration costs including mechanical interface and switchyard for LTE[a]	\$32 million	The total DCC is calculated by adding the installed DCC and the additional integration costs for LTE
NPP capacity factor	93%	The averaged factors for all the plant in US.
NPP thermal efficiency	34%	The averaged factors for all the plant in US.

[1] Jacob Prosser et al. (2024). Cost Analysis of Alternative Large-Scale High-Temperature Solid Oxide Electrolysis Hydrogen Production Facilities. International Journal of Hydrogen Energy 49, pp. 207–227 http://dx.doi.org/10.2139/ssrn.4898266

[2] Tyler Westover, et al. (April 18, 2023). Preconceptual Designs of Coupled Power Delivery between a 4-Loop PWR and 100-500 MWe HTSE Plants. INL/RPT-23-71939, Rev 1. https://www.osti.gov/biblio/2203699

Location-dependent Parameters

Parameter	Waterford	Riverbend	Grand Gulf	South Texas	Comanche Peak
Electricity price	$35/MWh	$35/MWh	$35/MWh	$31/MWh	$20/MWh
State Tax	9.45%	9.45%	9.45%	6.25%	8.25%
WACC	5.66%	5.66%	5.66%	5.73%	5.69%

Financial performance for NPP producing hydrogen before and after tax credits

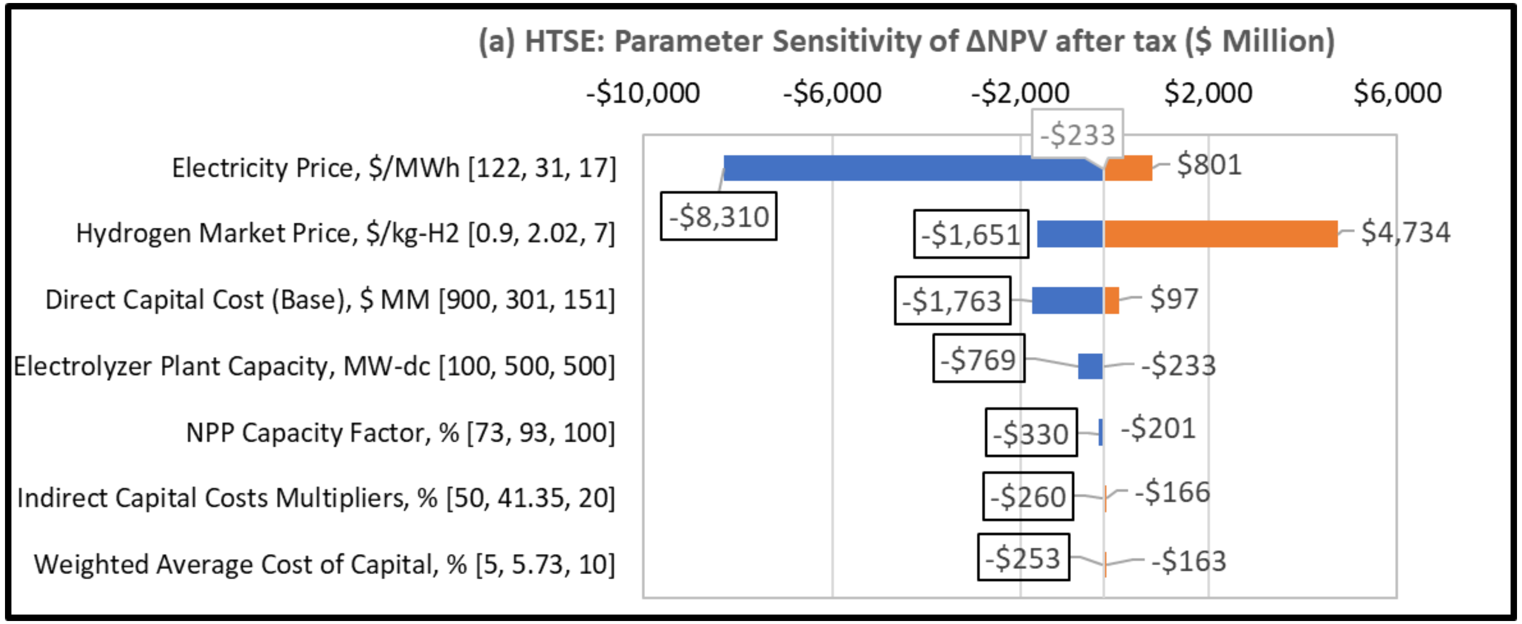
Assumes 500 MWe design for H2 plant but only 200 MWe qualifies for 45V Tax credits

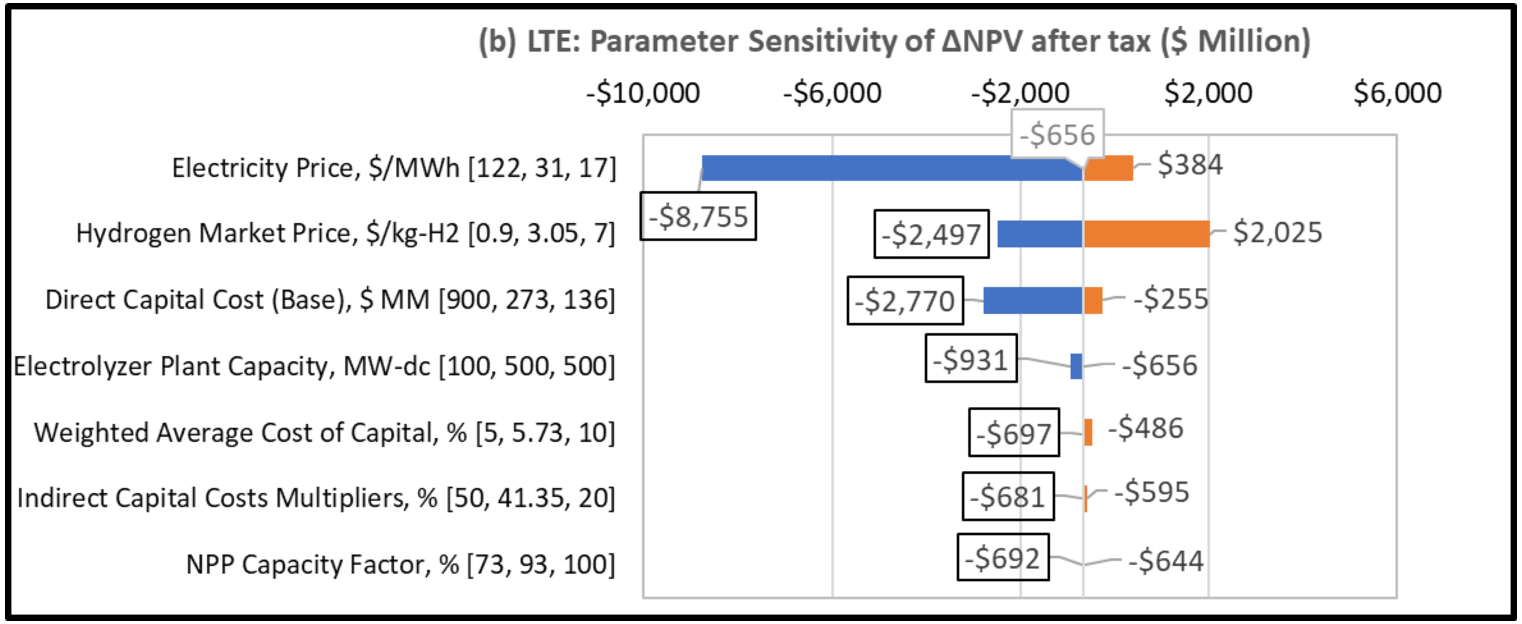
	Nuclear Plants	Waterford		Riverbend		Grand Gulf		South Texas			Comanche Peak		
		Before Tax	After Tax Credit	Before Tax	After Tax Credit	Before Tax	After Tax Credit	Before Tax	After Tax Credit	After Tax Credit (new)	Before Tax	After Tax	After Tax Credit (new)
LCOH ($/kg-$H_2$)	HTSE-pipeline	$2.08	$0.25	$2.08	$0.25	$2.08	$0.28	$1.92	$0.09	$1.23	$1.49	-$0.27	$0.87
	HTSE-industry	$2.08	$0.25	$2.08	$0.25	$3.00	$1.25	$1.92	$0.08	$1.23	$1.67	-$0.11	$1.04
	LTE-pipeline	$3.18	$1.41	$3.18	$1.41	$3.18	$1.44	$2.95	$1.16	$2.31	$2.31	$0.63	$1.78
	LTE-industry	$3.18	$1.41	$3.18	$1.41	$3.90	$2.21	$2.95	$1.16	$2.30	$2.47	$0.75	$1.89
LCOH+COD ($/kg-$H_2$)	HTSE-pipeline	$2.17	$0.34	$2.18	$0.35	$2.27	$0.47	$2.02	$0.19	$1.33	$1.86	$0.10	$1.24
	HTSE-industry	$2.18	$0.35	$2.18	$0.35	$3.24	$1.49	$2.01	$0.17	$1.32	$1.96	$0.18	$1.33
	LTE-pipeline	$3.29	$1.50	$3.29	$1.52	$3.40	$1.66	$3.06	$1.27	$2.42	$2.79	$1.11	$2.26
	LTE-industry	$3.29	$1.51	$3.29	$1.52	$4.14	$2.45	$3.04	$1.25	$2.39	$2.76	$1.04	$2.18
ΔNPV ($M) = $NPVH_2$-NPV_{BAU}	HTSE-pipeline	-$1687	$1219	-$1674	$1228	-$1552	$1316	-$1459	$1306	-$233	-$532	$1950	$408
	HTSE-industry	-$1674	$1228	-$1674	$1228	-$119	$105	-$1472	$1296	-$243	-$201	$583	$100
	LTE-pipeline	-$1769	$292	-$1769	$305	-$1651	$378	-$1531	$389	-$649	-$619	$1019	-$21
	LTE-industry	-$1760	$299	-$1760	$305	-$199	$43	-$1549	$376	-$663	-$377	$421	-$75

*LCOH: Levelized cost of Hydrogen
*COD: Cost of Delivery

*Entergy plants being a regulated public utility may not qualify for 45V being in a non-competitive market

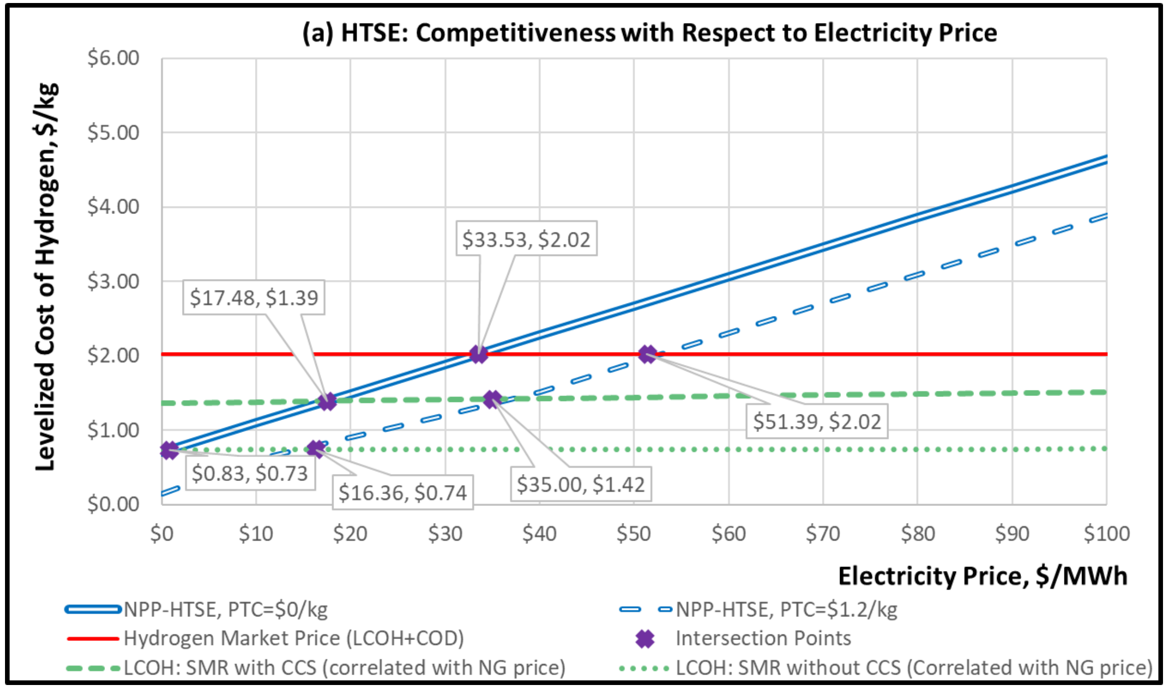
Sensitivity Analysis STP (∆NPV after tax credit)

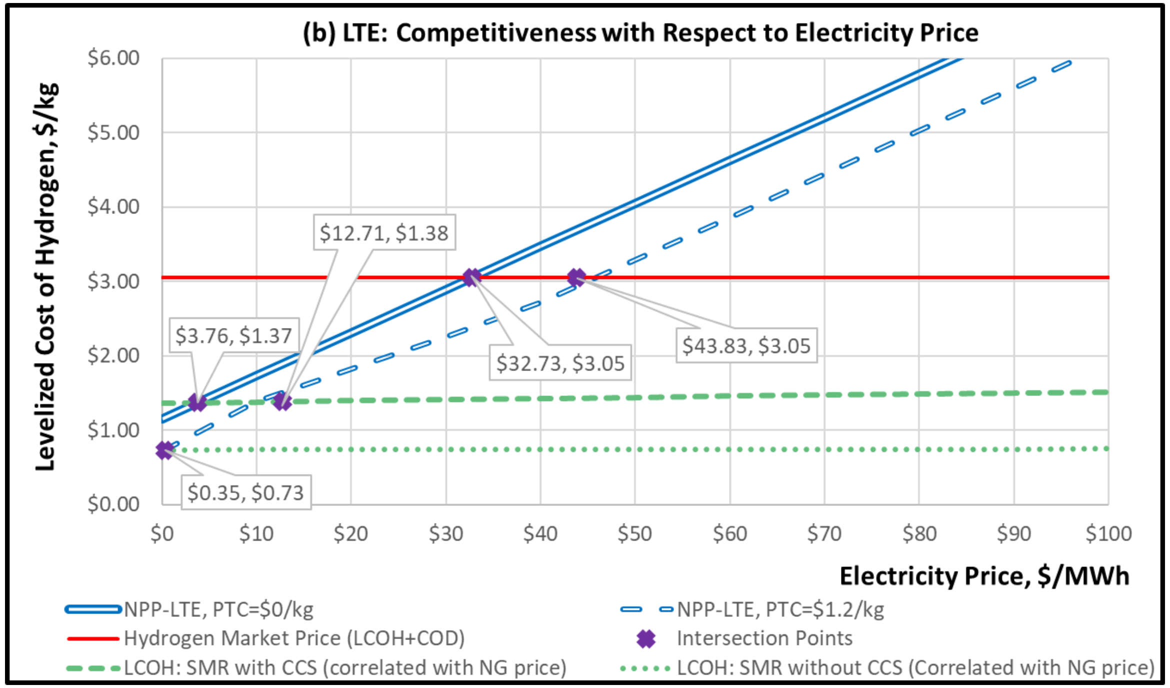




Comparisons with blue Hydrogen (LCOHs vs. elec price)

For example, for NPP-HTSE (left), H_2 sale price of $2/kg-H2:
-W/o PTC, LCOH would have to be $1.39/kg-H2 to compete with SMR LCOH w/ CCS
-W/ PTC of $1.2/kg-H2, LCOH would have to be $1.42 @ 35 $/MWh electricity price





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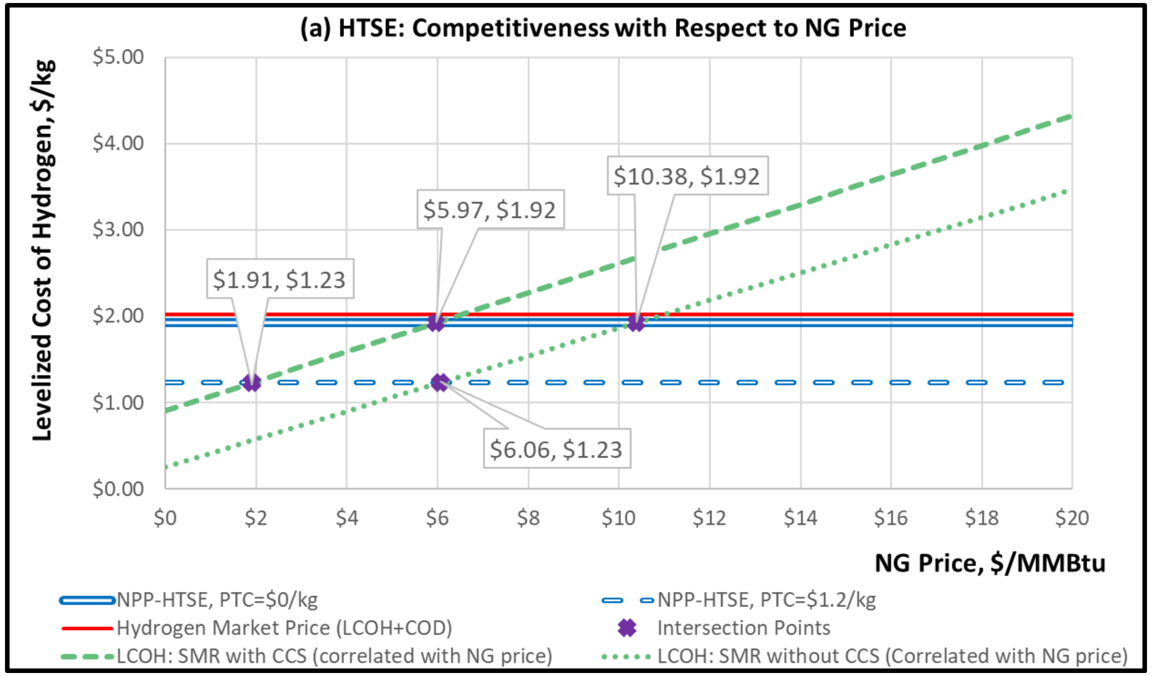
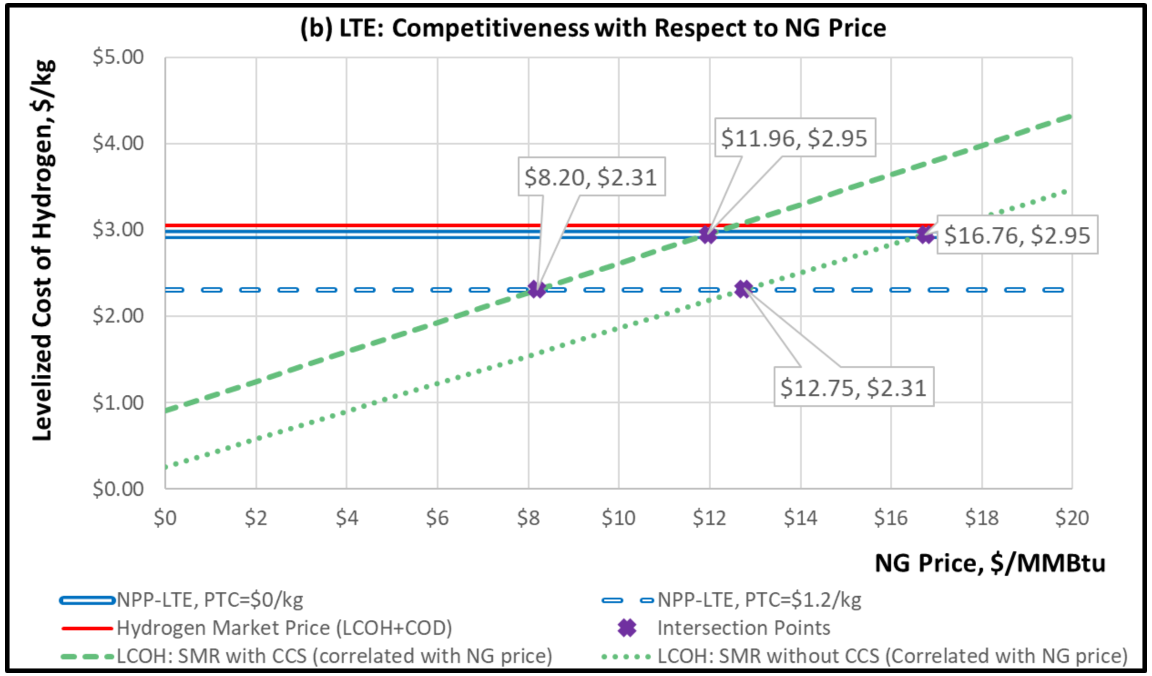
LIGHT WATER REACTOR SUSTAINABILITY

Comparisons with blue Hydrogen (LCOHs vs. NG price)



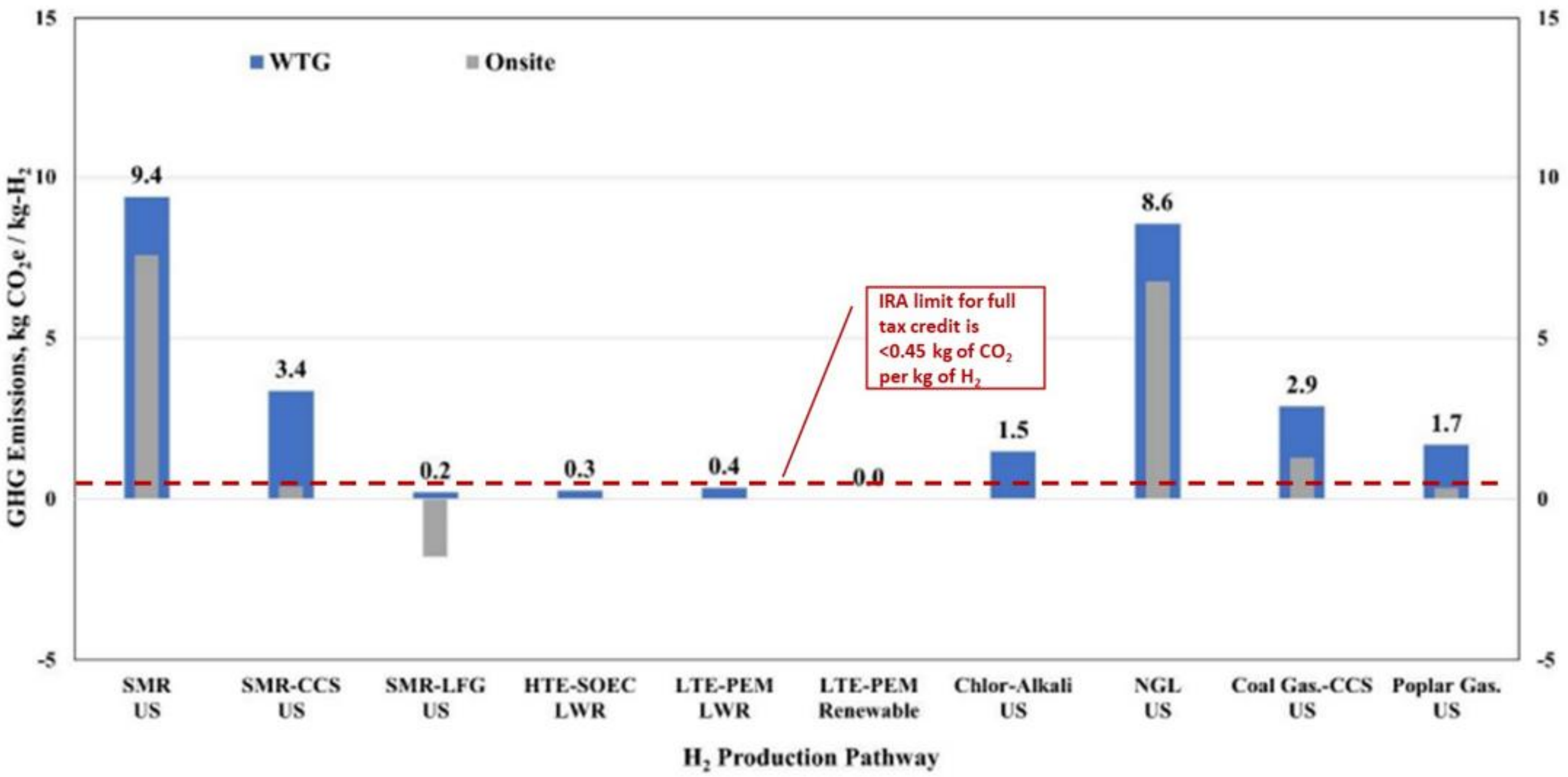


Competitive analysis with respect to natural gas for hydrogen production through (a) HTSE or (b) LTE with 500 MW-dc of electrolysis design capacity, 20 years of plant life, 5.73% of WACC, user-defined electricity fixed price, and hydrogen market price equivalent to summation of LCOH and COD.

Total Carbon Emissions Reduction

- NG-SMR pathway:
  9.4 kg CO2e/kg H2

- Nuclear HTE-SOEC:
  0.35 kgCO2e/kg H2



https://www.energy.gov/sites/default/files/2023-12/greet-manual_2023-12-20.pdf

Capacity	H2 Production (tonnes/day)	NPP HTE-SOEC Emissions (kg CO2e/day)	NG-SMR (kg CO2e/day)	Delta CO2e (kg CO2e/day)
500 MW	351	122,850	3,299,400	3,176,550

FY25~ Main Goal and Objective

- Designing and implementing configurations for delivering nuclear heat to industrial customers.
- Developing a thermal energy transport loop to transfer heat to industrial customers.
- Conducting both time-dependent and steady-state techno-economic analyses (TEA) to understand the long-term viability and ensure consistent evaluation of these applications.
- Develop an integrated decision-making framework that incorporates cost and risk analysis.

Explore and develop hybrid non-grid applications of Light Water Reactor (LWR) nuclear energy, specifically focusing on using the generated electricity and heat to produce hydrogen and supply heat to nearby industries.

Case Study Selection~ Industrial Heat Opportunities

Light Water Reactor in Gulf Coast Region

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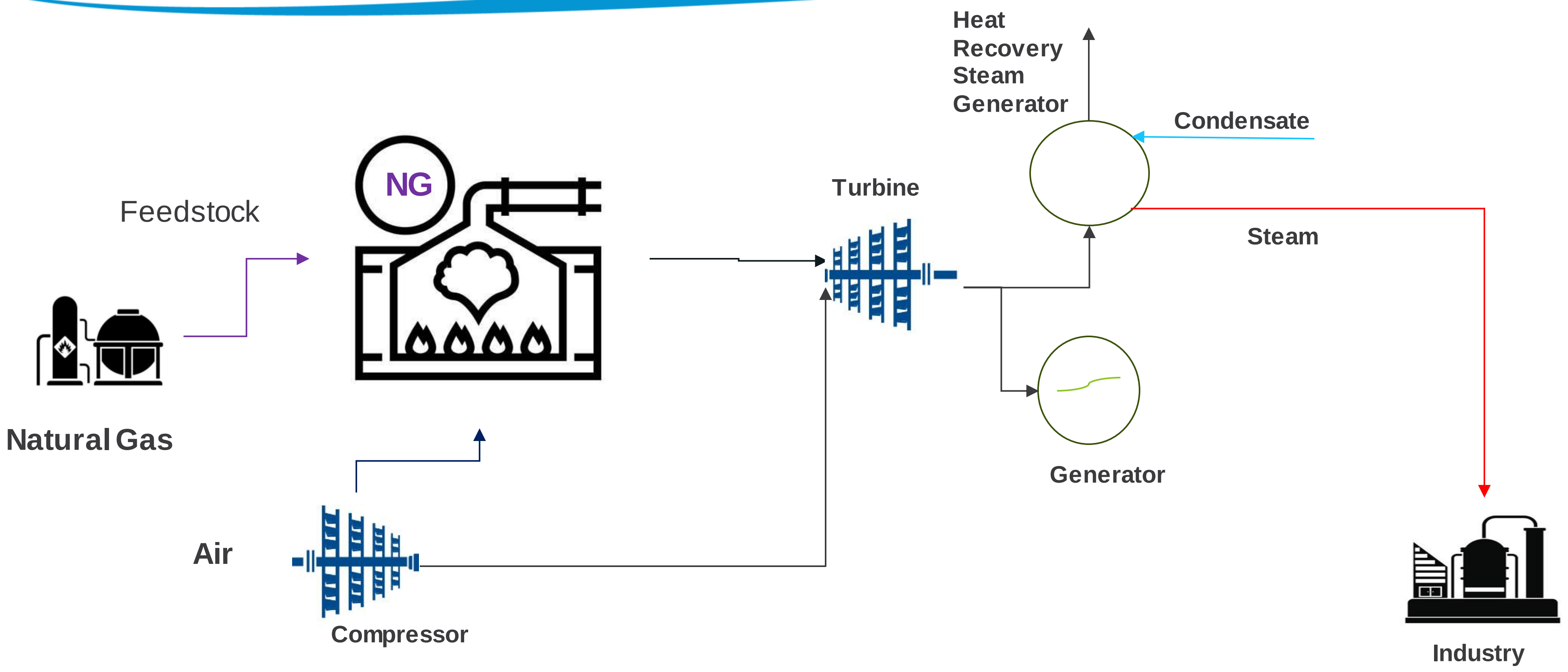
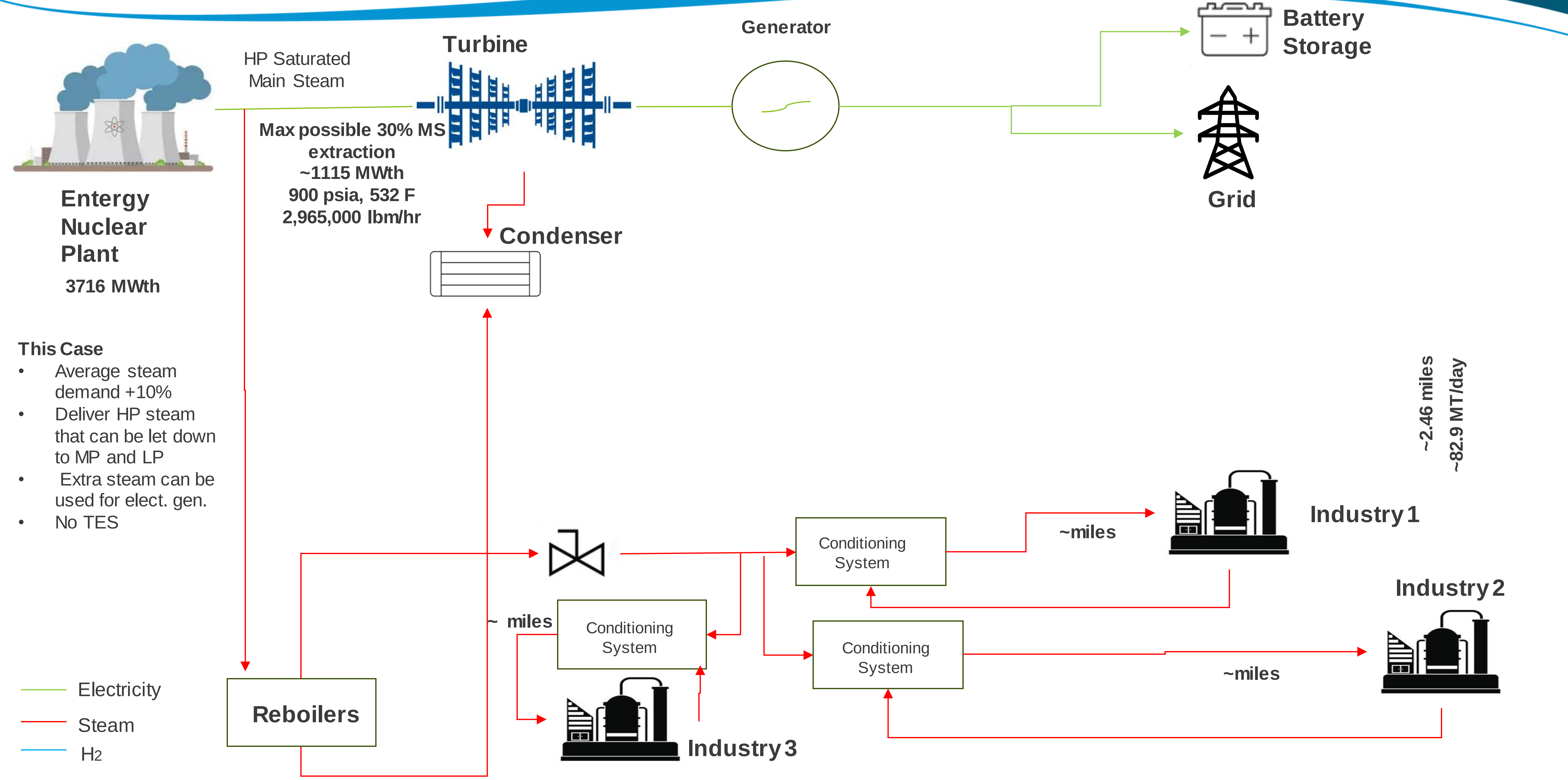
- Industries Within the Maximum Heat Delivery Distance (~10 miles)
- Heat Demand
- Hydrogen demand is also considered based on the selected industries

Steady State Case Definitions TEA

Case 0: Base case/industry standard



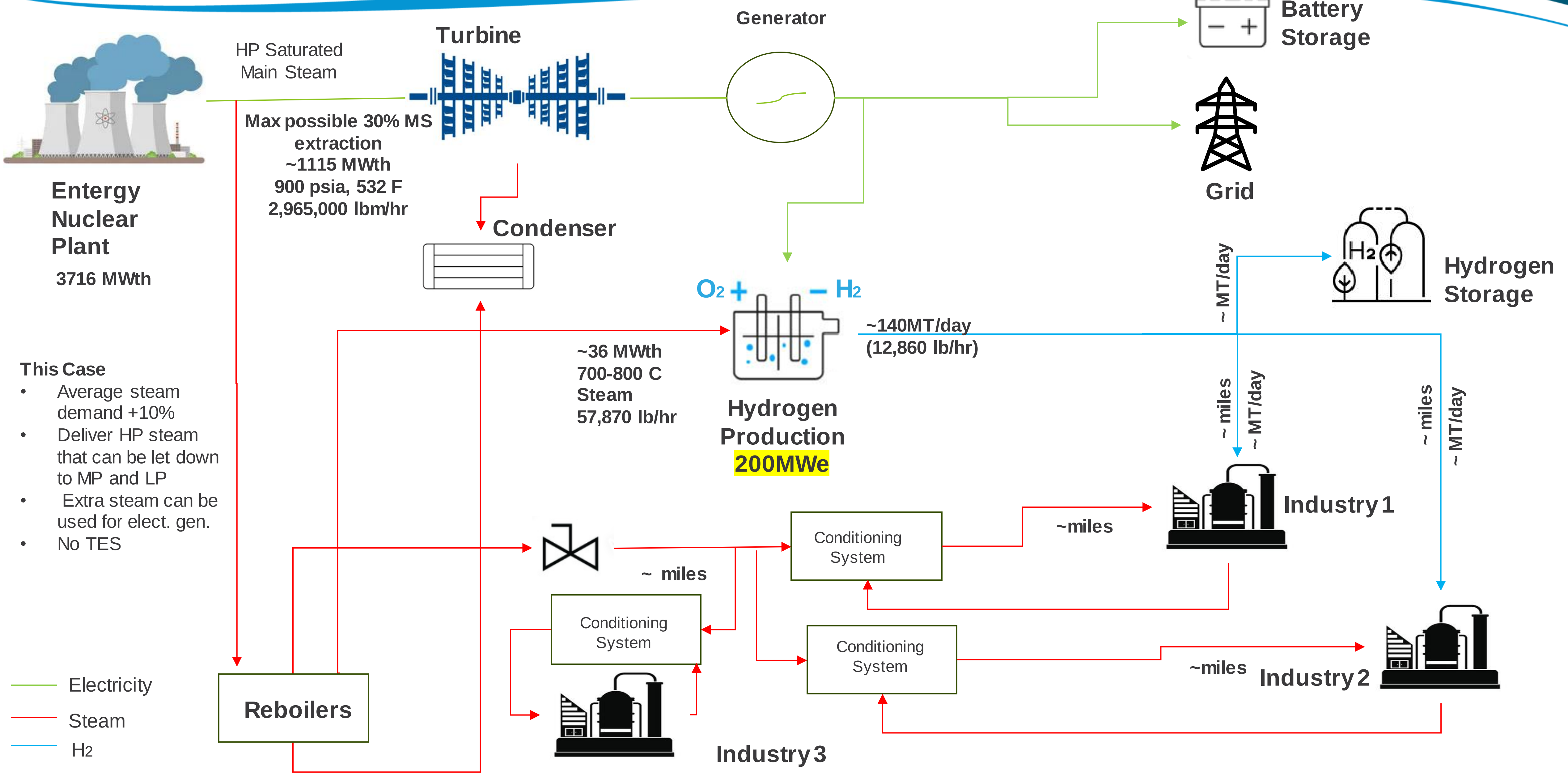
Case 1: Steady State case providing baseload steam demand



This Case

- Average steam demand +10%
- Deliver HP steam that can be let down to MP and LP
- Extra steam can be used for elect. gen.
- No TES

Case 2: Static case providing baseload steam demand



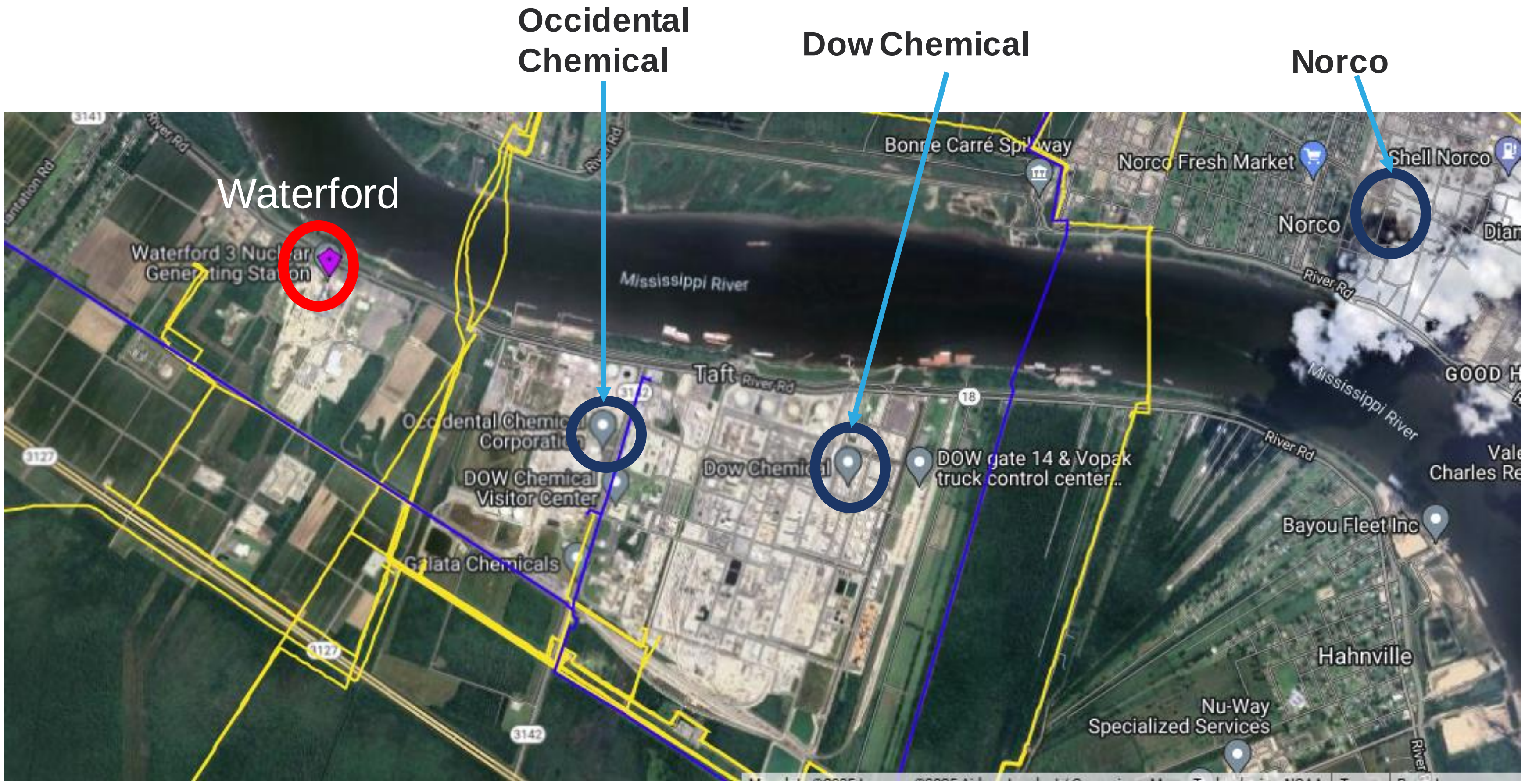
This Case
- Average steam demand +10%
- Deliver HP steam that can be let down to MP and LP
- Extra steam can be used for elect. gen.
- No TES

Waterford

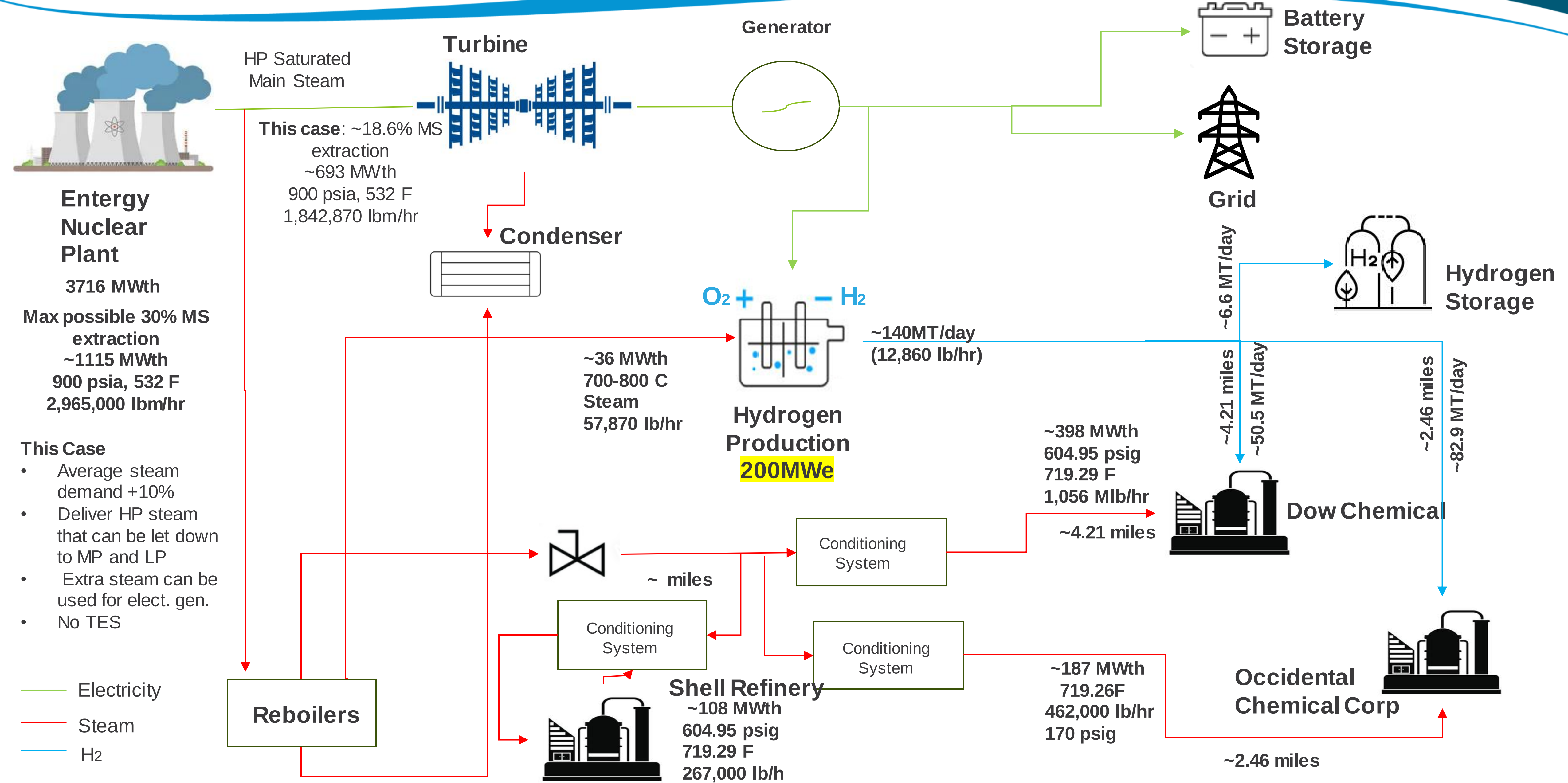
Waterford

Candidates

- Dow Chemical
- Occidental Chemical
- Norco



Data Collection for Waterford NPP



Data Collected for the Delivery of Nuclear Steam and Hydrogen from Waterford to Dow Chemical

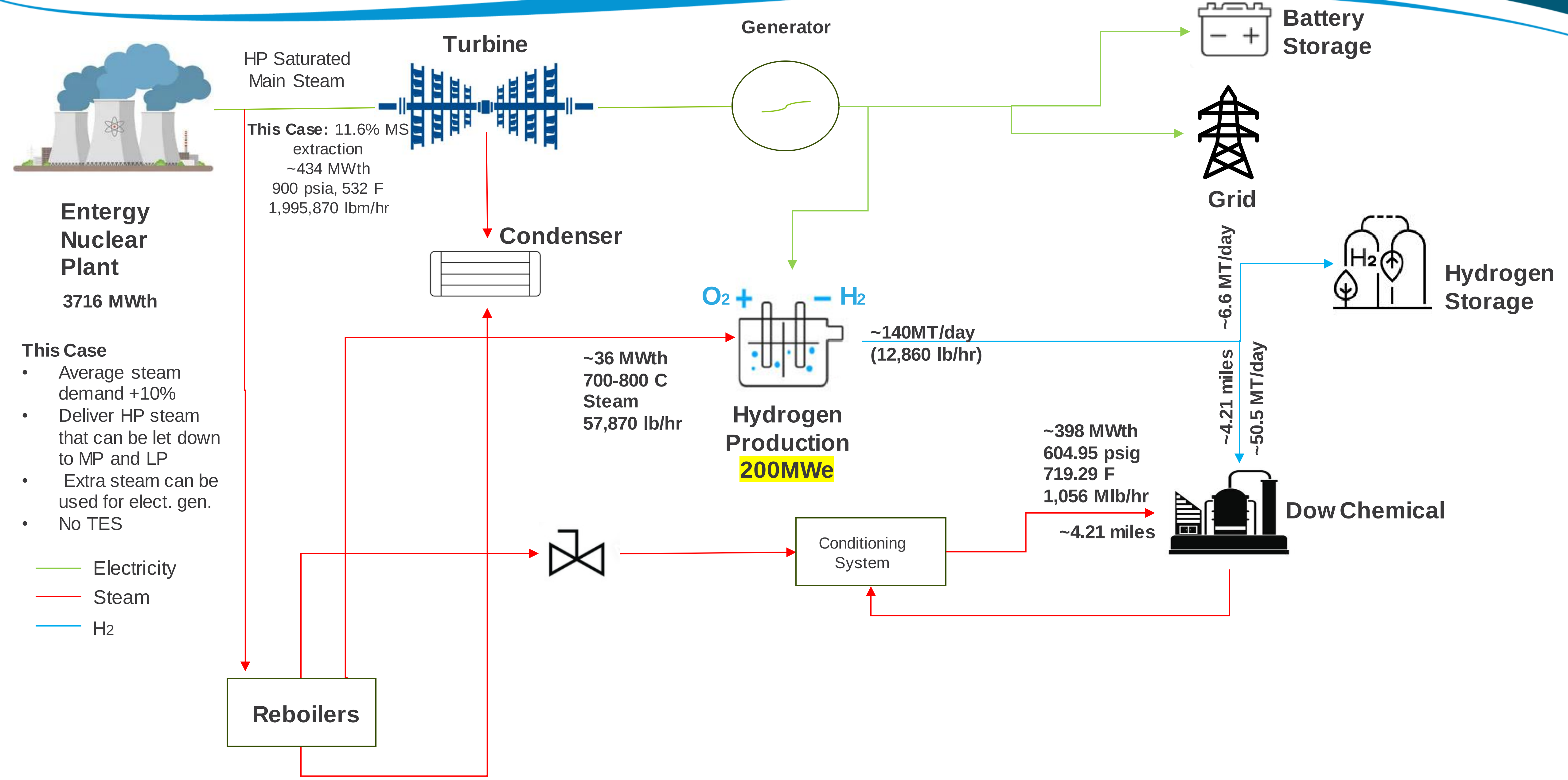
Waterford

~4.21 miles

Dow Chemical

Pipe Segment	Industrial User	Thermal Demand (MWth)	Length (mi)	H_2 demand (mt/day
1	-		0.5	
2	-		2.71	
4	**Dow**	398	1.0	50.5

Steady State Data collection case providing baseload steam and Hydrogen demand~ Dow

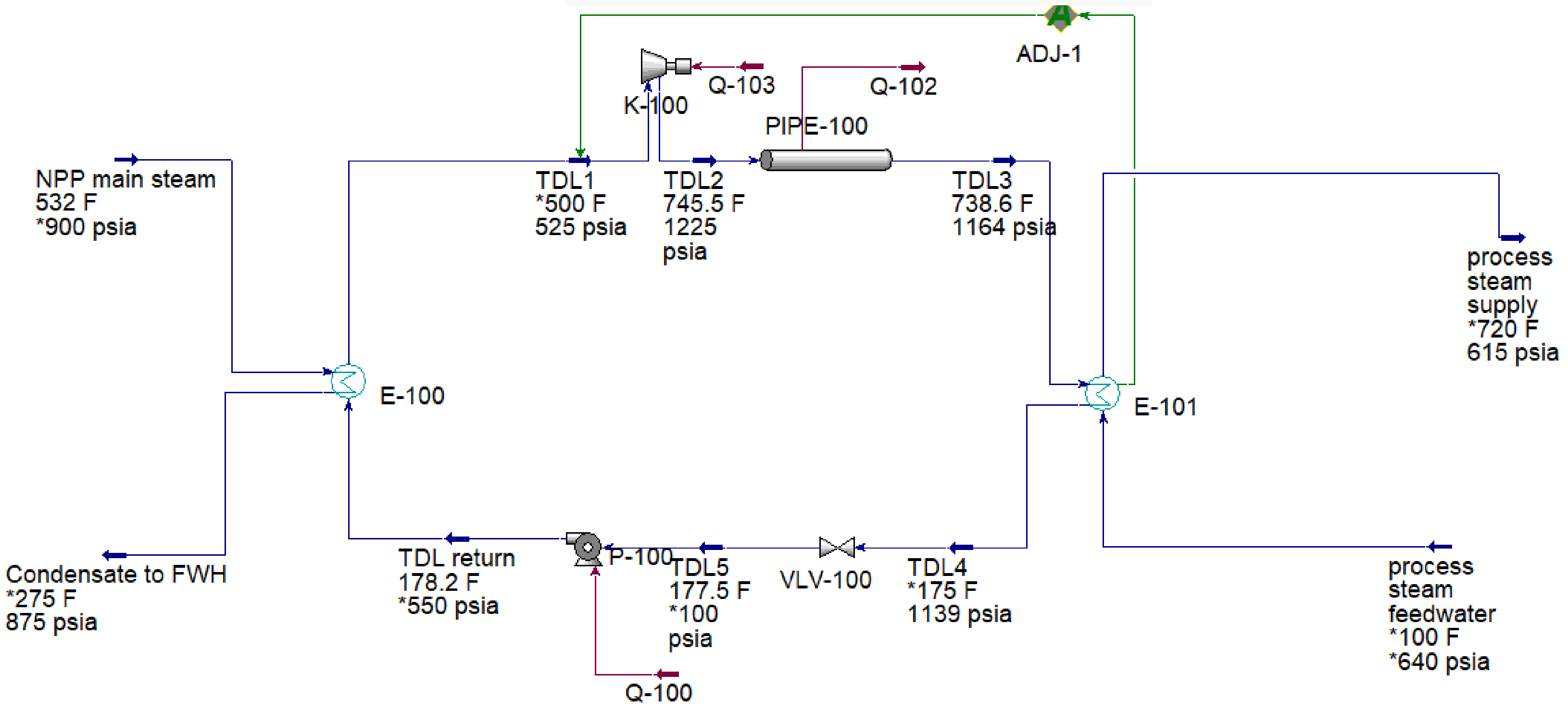


This Case

- Average steam demand +10%
- Deliver HP steam that can be let down to MP and LP
- Extra steam can be used for elect. gen.
- No TES

Initial Modeling Set Thermal Delivery Loop Model~Dow

- Vapor compression required to deliver HP steam with specified superheat
- Calculate heat loss in pipeline from NPP to industry
- Adjust superheat by adjusting pressure of TDL return


Compressor Rotor Power

Total Rotor [hp]	5.050e+004
Transient Rotational [hp]	0.0000
Friction Loss [hp]	0.0000
Fluid [hp]	5.050e+004

Dow~2 miles

Inputs

TDL 2

Parameter	Value
Final Temperature	396.4 C (745.5 F)
Final Pressure	84.5 bar (1225 psi)
Mass Flow Rate	143.3 kg/s (1.137e+6 lb/hr)

Process steam supply

Parameter	Value
Final Temperature	382.2 C (720 F)
Final Pressure	42.4 bar (615 psi)
Mass Flow Rate	132.4 kg/s (1.051e+6 lb/hr)

Assumptions

Parameter	Value
Return Temp	50 C (122 F)
Distance	3.2km (2 miles)
Q loss Max	2%
Pipe Material	SS-316
Pipe Mat Cost	$7/kg
Insulation Material	Mineral Fiber
Insulation Mat Cost	$12.3/kg
Electricity Cost (pump)	$0.168/kWe
Project Lifetime	30 yr
Interest Rate	5%
Max Velocity	50 m/s

TDL 2

- NPS 24 Sch 80
- Insulation Thickness 49mm
- Pressure drop 11.7 bar
- Temperature Drop 19.6 C
- Total Length 6km
- 106 Expansion Loops
- Pipe mat OCC $18.99 M
- Pipe ins OCC $92,000
- Pipe OPEX Cost $6.94 M/yr

Process Steam Supply

- NPS 24 Sch 40
- Insulation Thickness 47mm
- Pressure drop 14.7 bar
- Temperature Drop 26 C
- Total Length 6km
- 101 Expansion Loops
- Pipe mat OCC $10.88 M
- Pipe ins OCC $87,100
- Pipe OPEX Cost $14.7 M/yr

Conclusion

- Quite large pressure drops, could be reduced but would require larger more expensive pipes.
- The expansion loops almost double the length of the pipeline due to the high operating temperatures.
- Parallel pipelines would reduce pressure drop and operating cost, while increasing capital cost.
- Would need around 450 supports for each pipeline (every 12.8 m for NPS 24).
- Cost for supports, labor, and welding not included.

Updated Waterford Case Inputs

Common Inputs

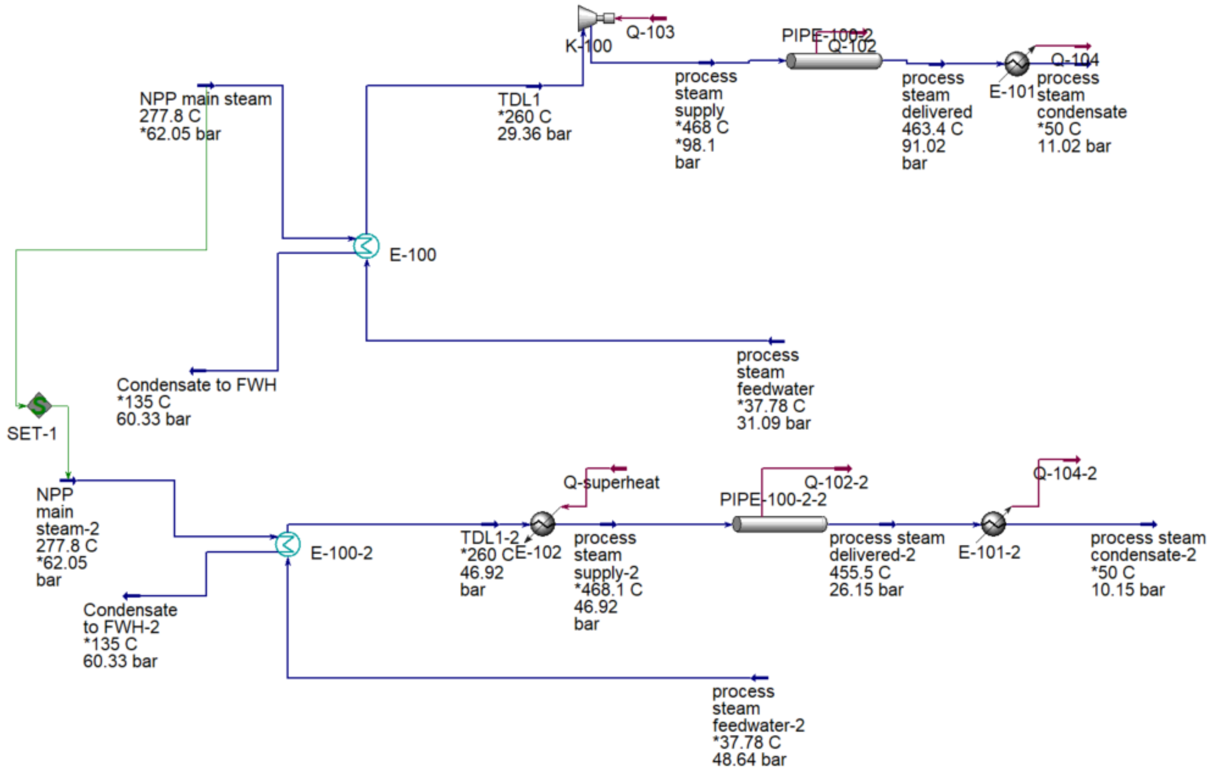
Parameter	Value
Pipe material	SS-316
Insulation material	Mineral Fiber
Heat loss	1% per mile
Electricity price	$0.168/kWh
Delivered steam temperature	719.29 F (381.8 C)
Delivered steam pressure	604.95 psig (42.7 bara)
Project time	20 years
Discount rate	5%
Return condensate pressure	10 bara
Return condensate temperature	50 C

Note: OPEX is equal to the pump power required to pump condensate to overcome pressure drop along the pipe.

Pipe Segment	Industrial User	Thermal Demand	Length (miles)
1	-	-	0.50
2	-	-	1.35
3	Occidental	187	0.61
4	-	-	1.36
5	Dow	398	1.00

Note: Steam demand is assumed to be at the same conditions for both users, and flow rates are calculated to be thermal demand divided by the difference in the enthalpy between the delivered steam condition and condensate return condition, taking into account the heat loss along the pipe segments.

Modified Model



Inputs to Dow

Parameter	Value
Distance	4.21 mile (6.8 km)
Q delivered	398 MW
Q loss	16.75 MW
Mass flow rate	140.2 kg/s

Dow Chemical

Supply Pipe

Parameter	Value
Best Pipe	NPS 24 Sch 40
Insulation thickness	57.5 mm
Total annual cost	$2.96 M/yr
Total OCC	$24.69 M
OPEX	$0.98 M/yr
Number of Expansion Loops	123
Total pipe length	8.4 miles (13.5km)
Pressure drop	36.0 bar
Temperature drop	72.0 C

This would require the steam to be sent from the NPP at 78.7 bar and 453.8 C Because this pressure/Temperature is higher than what the NPP can provide the ΔP has to be made up with a compressor not a pump. This would increase the OPEX by ~30 times.

Return Pipe

Parameter	Value
Best Pipe	NPS 14 Sch 5
Insulation thickness	34.5 mm
Total annual cost	$0.46 M/yr
Total OCC	$3.38 M
OPEX	$0.18 M/yr
Number of Expansion Loops	284
Total pipe length	8.4 miles (13.5km)
Pressure drop	8.86 bar
Temperature drop	1.93 C

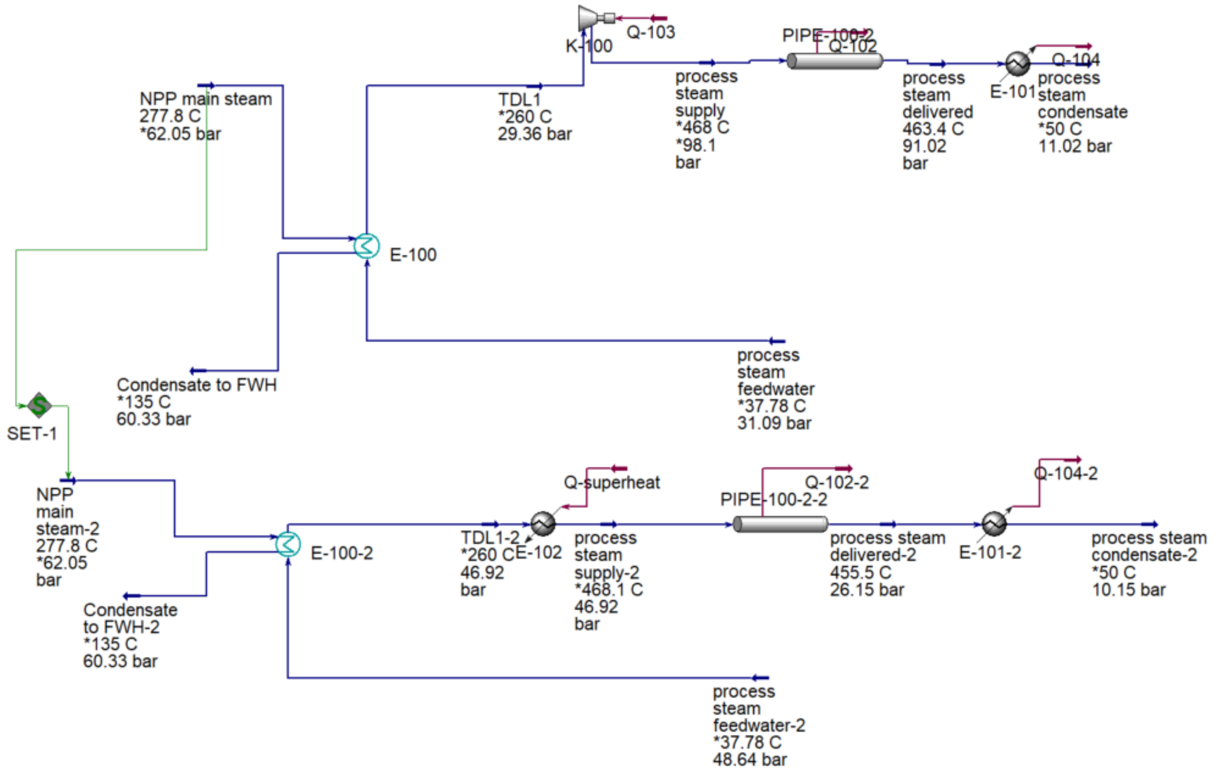
Condensate is returned to NPP at 1.14 bar and 8.86 C

Total Case 1 Costs

Parameter	Value
Total annual cost	$3.42 M/yr
Total OCC	$28.07 M
OPEX	$1.16 M/yr

Results

MVC power requirement: 53.2 MW



Electrical heater power requirement: 77.9 MW

- MVC pressure ratio: 3.070
- Rerun analysis for electrical heating case with a specified pressure drop of 4.22 bar

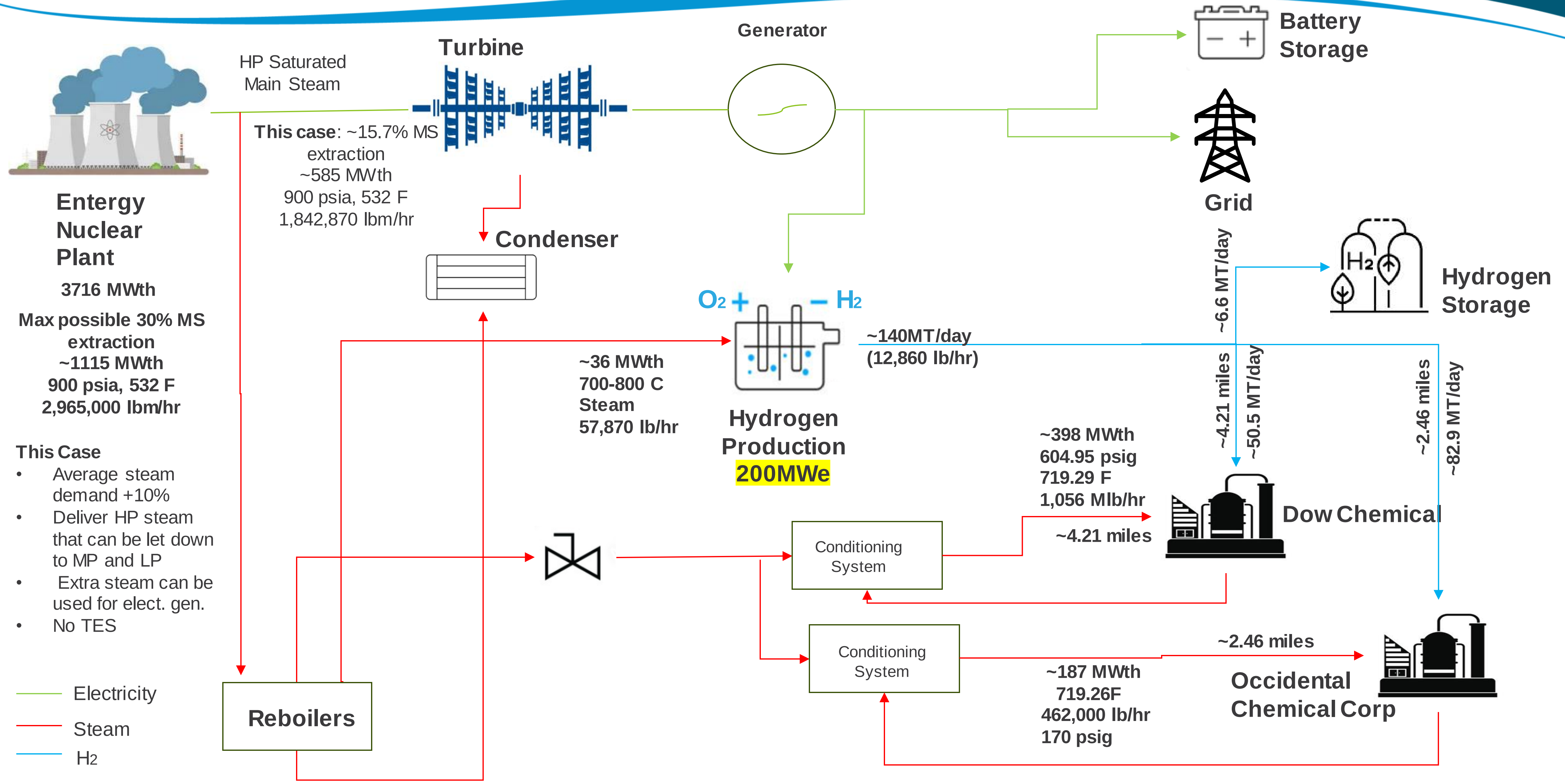
Waterford

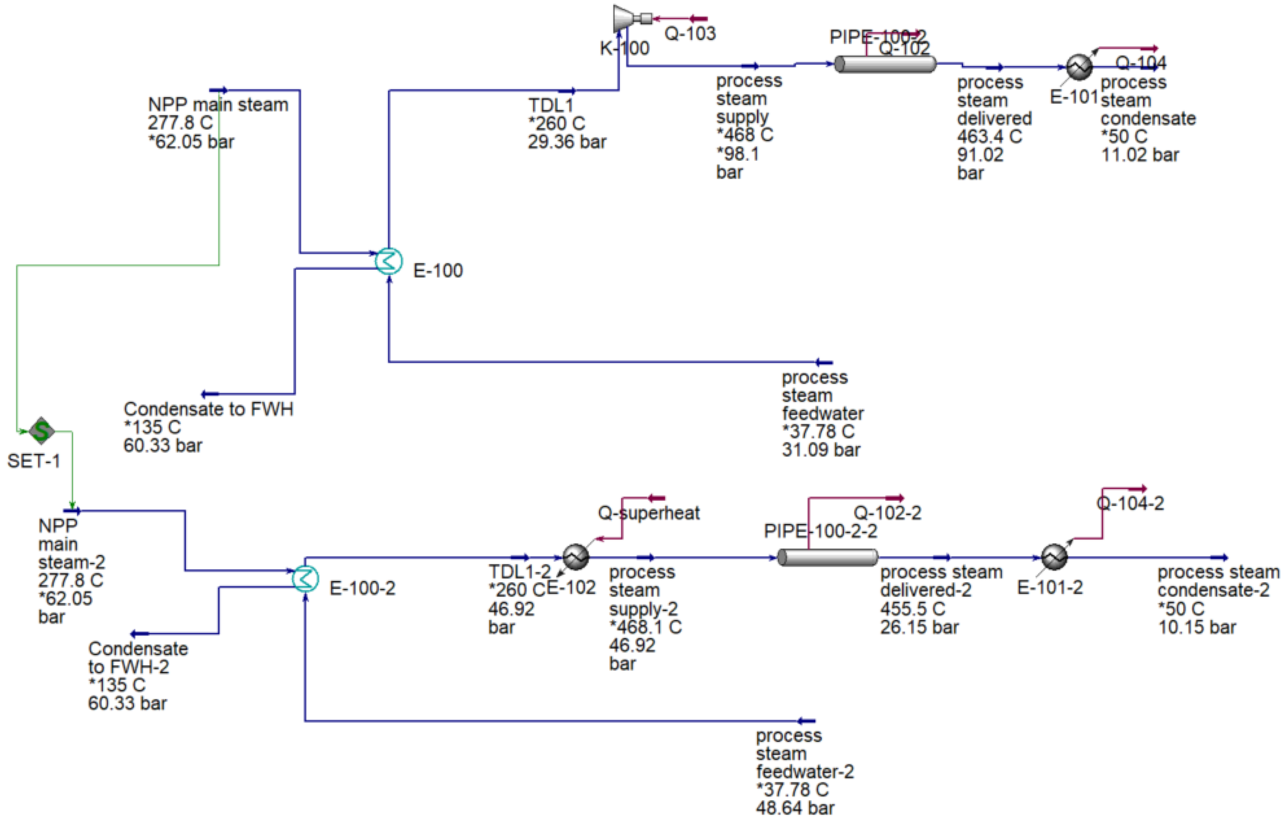
~4.21 miles → Dow Chemical

~2.46 miles → Occidental Chemical Corp

Pipe Segment	Industrial User	Thermal Demand (MWth)	Length (mi)	H_2 demand (mt/day
1	-		0.5	
2	-		2.71	
3	**Occidental Corp**		0.61	
4	**-**		1.36	
5	**Dow**	398	1.0	50.5

Steady State Data collection case providing baseload steam and Hydrogen demand~ Dow and Occidental Chemical Corp





Inputs

1+2

Parameter	Value
Distance	1.85 mile (2.98 km)
Q delivered	595.53 MW
Q loss	11.02 MW
Mass flow rate	197.80 kg/s

3

Parameter	Value
Distance	0.61 mile (0.98 km)
Q delivered	187 MW
Q loss	1.14 MW
Mass flow rate	63.23 kg/s

4+5

Parameter	Value
Distance	2.36 mile (3.80 km)
Q delivered	398 MW
Q loss	9.39 MW
Mass flow rate	134.57 kg/s

Dow and Occidental Corp

Supply Pipe

1+2

Parameter	Value
Best Pipe	NPS 24 Sch 60
Insulation thickness	38.5 mm
Total annual cost	$2.15 M/yr
Total OCC	$14.95 M
OPEX	$0.95 M/yr
Number of Expansion Loops	51
Total pipe length	3.7 miles (5.9km)
Pressure drop	24.0 bar
Temperature drop	36.6 C

3

Parameter	Value
Best Pipe	NPS 18 Sch 40s
Insulation thickness	92.0 mm
Total annual cost	$0.16 M/yr
Total OCC	$1.47 M
OPEX	$0.04 M/yr
Number of Expansion Loops	19
Total pipe length	1.2 miles (1.9km)
Pressure drop	3.71 bar
Temperature drop	10.3 C

4+5

Parameter	Value
Best Pipe	NPS 24 Sch 30
Insulation thickness	54.5 mm
Total annual cost	$1.34 M/yr
Total OCC	$11.35 M
OPEX	$0.43 M/yr
Number of Expansion Loops	67
Total pipe length	4.7 miles (7.5km)
Pressure drop	16.9 bar
Temperature drop	40.6 C

Because this pressure/Temperature is higher than what the NPP can provide the ΔP has to be made up with a compressor not a pump. This would increase the OPEX by ~30 times.

Return Pipe

1+2

Parameter	Value
Best Pipe	NPS 18 Sch 5
Insulation thickness	28 mm
Total annual cost	$0.23 M/yr
Total OCC	$2.01 M
OPEX	$0.07 M/yr
Number of Expansion Loops	113
Total pipe length	3.7 miles (5.9km)
Pressure drop	2.3 bar
Temperature drop	0.9 C

4+5

Parameter	Value
Best Pipe	NPS 18 Sch 5
Insulation thickness	44.5 mm
Total annual cost	$0.27 M/yr
Total OCC	$2.60 M
OPEX	$0.03 M/yr
Number of Expansion Loops	146
Total pipe length	4.7 miles (7.6 km)
Pressure drop	1.4 bar
Temperature drop	1.17 C

3

Parameter	Value
Best Pipe	NPS 10 Sch 5
Insulation thickness	66 mm
Total annual cost	$0.04 M/yr
Total OCC	$0.33 M
OPEX	$0.01 M/yr
Number of Expansion Loops	42
Total pipe length	1.2 miles (1.9km)
Pressure drop	1.0 bar
Temperature drop	0.3 C

Condensate is returned to the NPP at 6.3 bar and 48.2 C

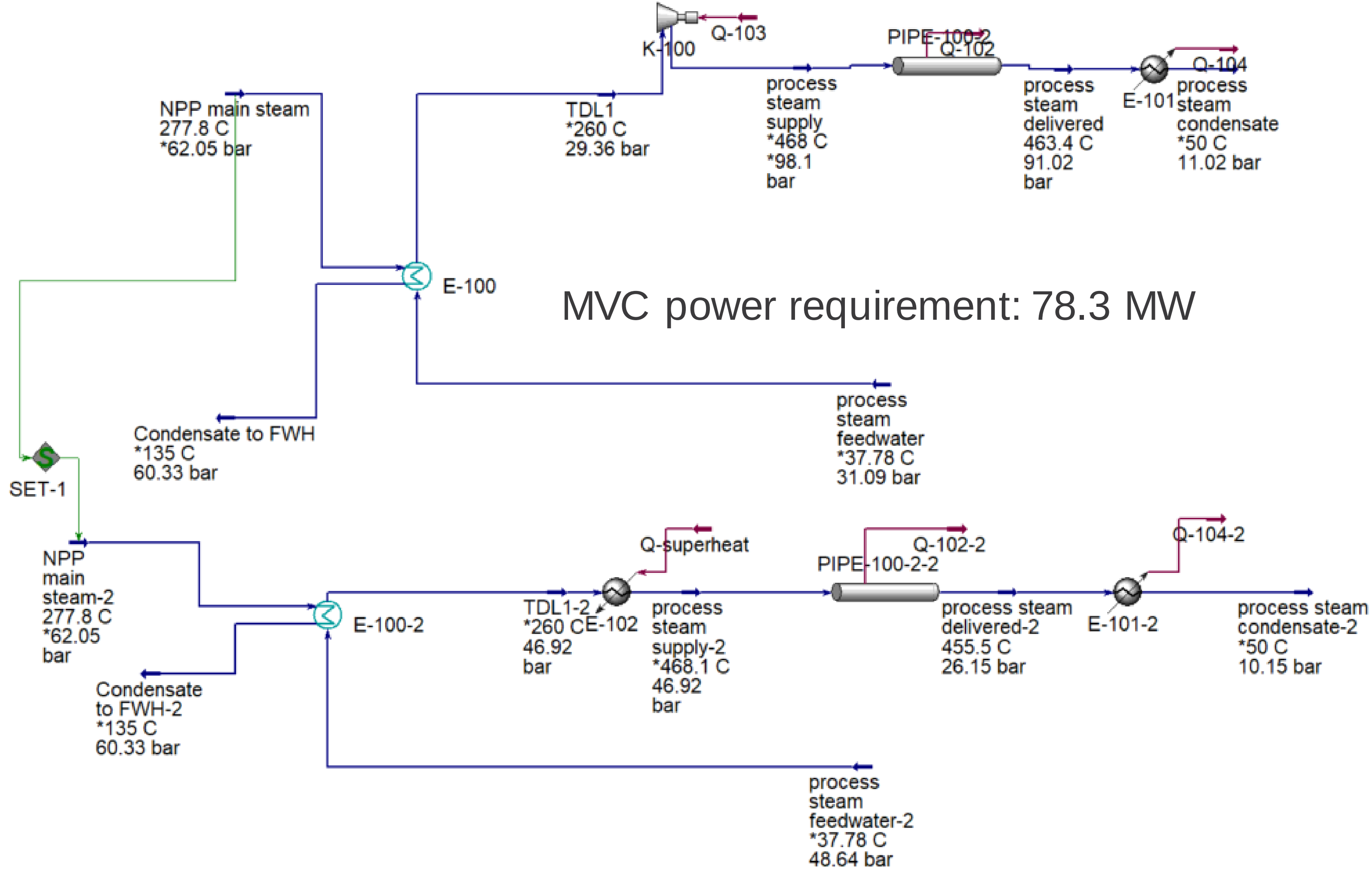
Total Case 2 Costs

Parameter	Value
Total annual cost	$4.19 M/yr
Total OCC	$32.71 M
OPEX	$1.53 M/yr

Model Results

MVC pressure ratio: 3.24

Rerun analysis for electrical heating case with a specified pressure drop of 4.22 bar



MVC power requirement: 78.3 MW

Electrical heater power requirement: 114.0 MW

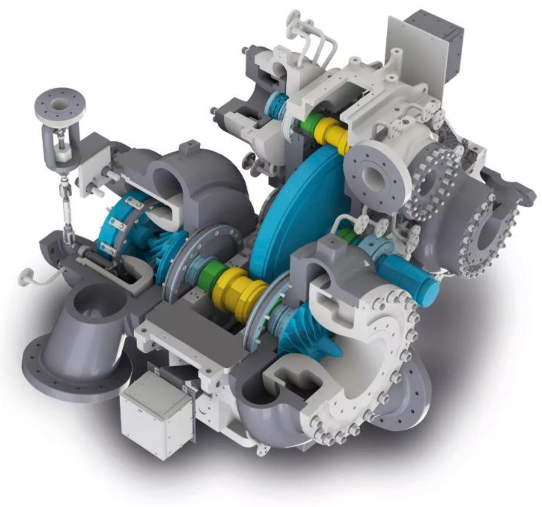
Equipment Costs

MVC:

- Atlas Copco: ongoing pilot project in Netherlands using mechanical vapor recompression (MVR) to upgrade low-pressure steam to supply energy.
  - Pressure ratio of ~4
  - COP 7.5 (every 1 MW electricity produces 7.5 MW thermal energy)
- Chart/Howden: MVR blower and compressor

Electrical resistance heating:

- Thermon Vapor Power
- Chromalox steam boiler
- HTSE topping heaters- high temp products



CROSS-SECTION OF AN INTEGRALLY GEARED COMPRESSOR CORE

Steam Integration Costs (SL-016181, Rev. 1)

- 105 MWth extraction case for integration with HTSE
- Provides costs for mods to divert steam

Area	Group	Phase	Description	Notes	Quantity	Subcontract Cost	Process Equipment Cost	Material Cost	Man Hours	Labor Cost	Equip Amount	Total Cost
1			**STEAM SUPPLY**									
	21.00.00		CIVIL WORK									
		21.17.00	EXCAVATION									
			FOUNDATION EXCAVATION, CLAY USING 1 CY BACKHOE	HYDROGEN INTERFACE EQUIPMENT	194.22 CY	-	-		53	4,224	935	5,158
			FOUNDATION EXCAVATION, CLAY USING 1 CY BACKHOE	(2) DRAIN COOLER FOUNDATIONS	39.56 CY	-	-		11	860	190	1,051
			FOUNDATION EXCAVATION, CLAY USING 1 CY BACKHOE	(2) DEMINERALIZED WATER TANK AND PUMP	203.33 CY	-	-		55	4,422	978	5,400
			FOUNDATION EXCAVATION, CLAY USING 1 CY BACKHOE	(2) STEAM REBOILER	217.33 CY	-	-		59	4,726	1,046	5,772
			TRENCH EXCAVATION 6FT TO 10FT DEEP, DENSE HARD CLAY USING 0.75 CY EXCAVATOR	BURIED R/O SUPPLY PIPE	1,174.46 CY	-	-		106	8,451	1,870	10,321
			EXCAVATION						284	22,683	5,019	27,701
		21.19.00	DISPOSAL									
			DISPOSAL OF EXCESS MATERIAL USING DUMP TRUCK, 4 MI ROUND TRIP	HYDROGEN INTERFACE EQUIPMENT	194.22 CY	-	-		19	1,491	330	1,821
			DISPOSAL OF EXCESS MATERIAL USING DUMP TRUCK, 4 MI ROUND TRIP	(2) DRAIN COOLER FOUNDATIONS	39.56 CY	-	-		4	304	67	371
			DISPOSAL OF EXCESS MATERIAL USING DUMP TRUCK, 4 MI ROUND TRIP	BURIED R/O SUPPLY PIPE	422.93 CY	-	-		30	2,435	539	2,973
			DISPOSAL OF EXCESS MATERIAL USING DUMP TRUCK, 4 MI ROUND TRIP	(2) DEMINERALIZED WATER TANK AND PUMP	203.33 CY	-	-		20	1,561	345	1,906
			DISPOSAL OF EXCESS MATERIAL USING DUMP TRUCK, 4 MI ROUND TRIP	(2) STEAM REBOILER	217.33 CY	-	-		21	1,668	369	2,037
			DISPOSAL						93	7,458	1,650	9,108
		21.20.00	BACKFILL									
			FOUNDATION BACKFILL, SELECT STRUCTURAL FILL	HYDROGEN INTERFACE EQUIPMENT	70.02 CY	-	-	2,241	17	1,344	297	3,882
			FOUNDATION BACKFILL, SELECT STRUCTURAL FILL	(2) DRAIN COOLER FOUNDATIONS	36.29 CY	-	-	1,161	9	696	154	2,012
			FOUNDATION BACKFILL, SELECT STRUCTURAL FILL	(2) DEMINERALIZED WATER TANK AND PUMP	87.51 CY	-	-	2,800	21	1,679	372	4,851
			FOUNDATION BACKFILL, SELECT STRUCTURAL FILL	(2) STEAM REBOILER	122.16 CY	-	-	3,909	29	2,344	519	6,772
			TRENCH BACKFILL, PREVIOUSLY EXCAVATED MATERIAL	BURIED R/O SUPPLY PIPE	1,045.14 CY	-	-		125	10,027	2,219	12,246
			TRENCH BACKFILL, SAND BEDDING	BURIED R/O SUPPLY PIPE	400.66 CY	-	-	6,811	63	4,997	1,106	12,914
			BACKFILL					16,923	264	21,087	4,666	42,676
		21.43.00	FENCEWORK									
			SECURITY AND FENCING MODIFICATIONS		1.00 LS	200,000	-					200,000
			FENCEWORK			200,000						200,000
		21.54.00	CAISSON									
			3 FT DIA X 6 FT DEEP CAISSON	PIPE RACK PIERS - EACH CAISSON = 1.57CY X $1,300 = $2,041 EA.	180.00 EA	367,380	-					367,380
			CAISSON			367,380						367,380
			CIVIL WORK			567,380		16,923	641	51,227	11,335	646,865
	22.00.00		CONCRETE									
		22.13.00	CONCRETE									
			MAT FOUNDATION LESS THAN 5 FT THICK, 4500 PSI	HYDROGEN INTERFACE EQUIPMENT	133.33 CY	-	-	19,333	267	18,216	3,472	41,021
			MAT FOUNDATION LESS THAN 5 FT THICK, 4500 PSI	(2) DRAIN COOLER FOUNDATIONS	8.00 CY	-	-	1,160	16	1,093	208	2,461
			MAT FOUNDATION LESS THAN 5 FT THICK, 4500 PSI	(2) DEMINERALIZED WATER TANK AND PUMP	127.24 CY	-	-	18,449	254	17,383	3,313	39,145
			MAT FOUNDATION LESS THAN 5 FT THICK, 4500 PSI	(2) STEAM REBOILER	111.11 CY	-	-	16,111	222	15,180	2,893	34,184
			CONCRETE					55,053	759	51,872	9,887	116,812

South Texas Project

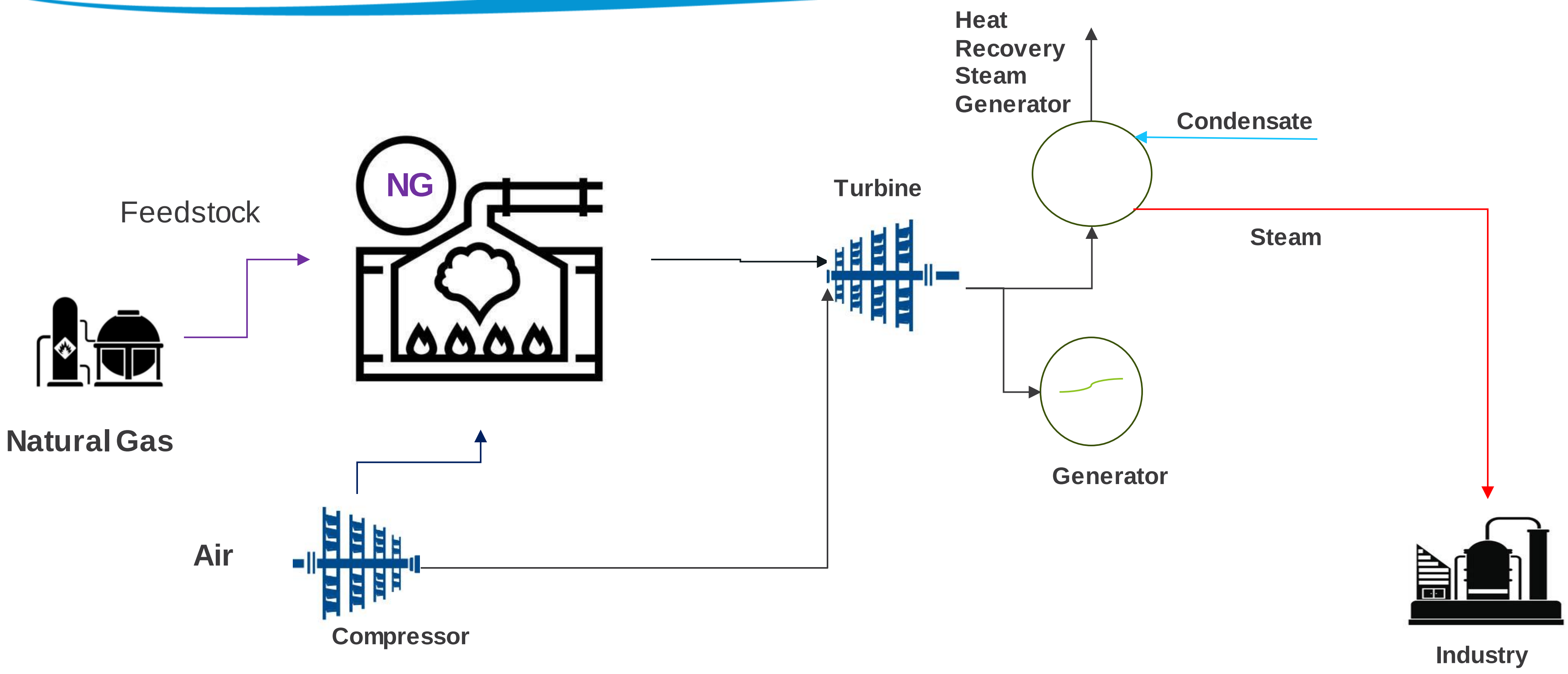
Current Market

Pipe Segment	Industrial User	Thermal Demand (MWth)	Length (mi)
1	-		6.11
2	LyondellBasell		0.12

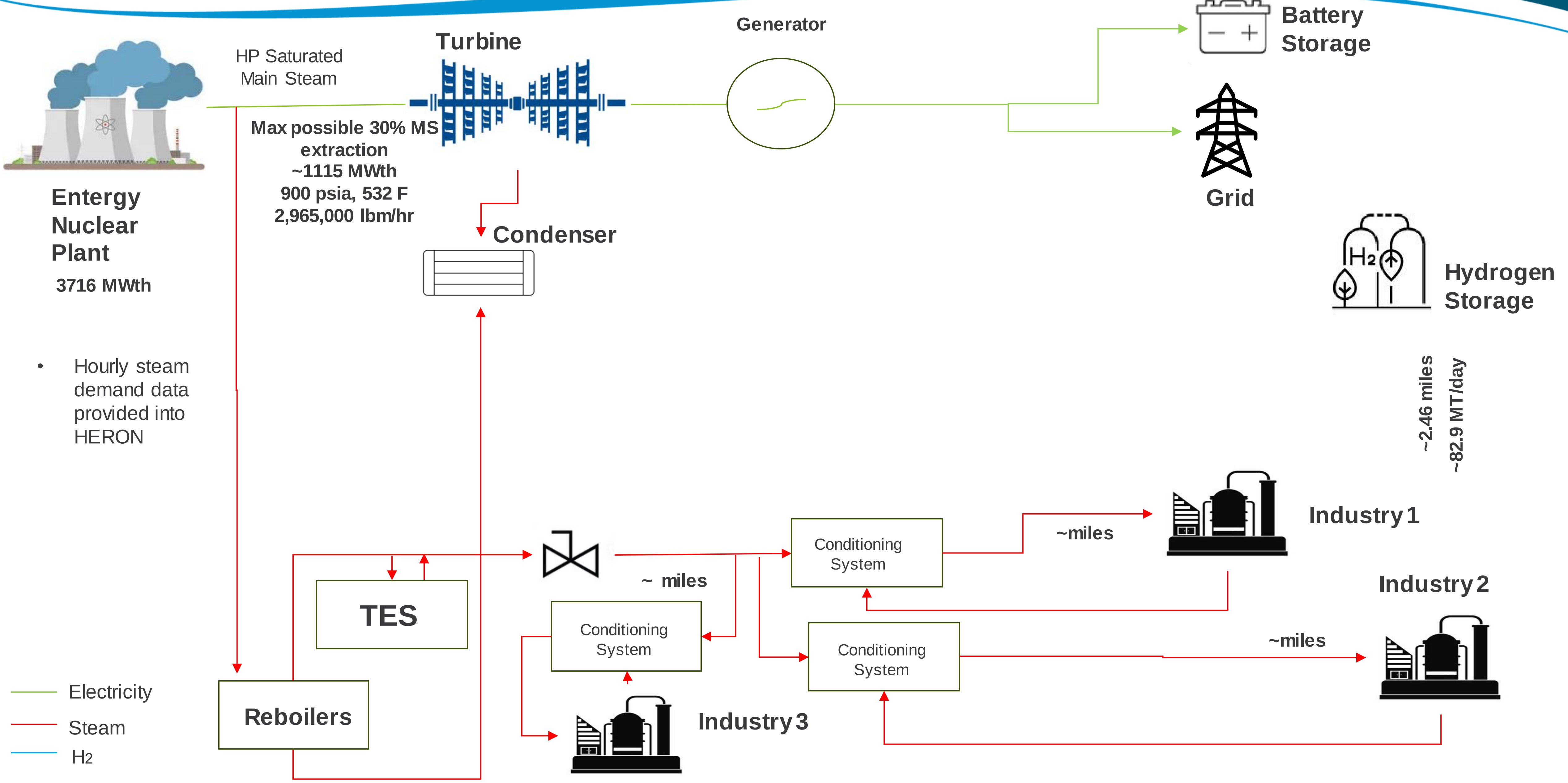
Pipe Segment	Industrial User	Thermal Demand (MWth)	Length (mi)
1	-		4.71
2	Rohem America		1.35
3	-		0.11
4	Oxea Corporation		1.40
5	-		0.36
6	EFG Polymer		1.70

Future Market~ HIF Global~2 miles

Case 0: Dynamic Base case/industry standard

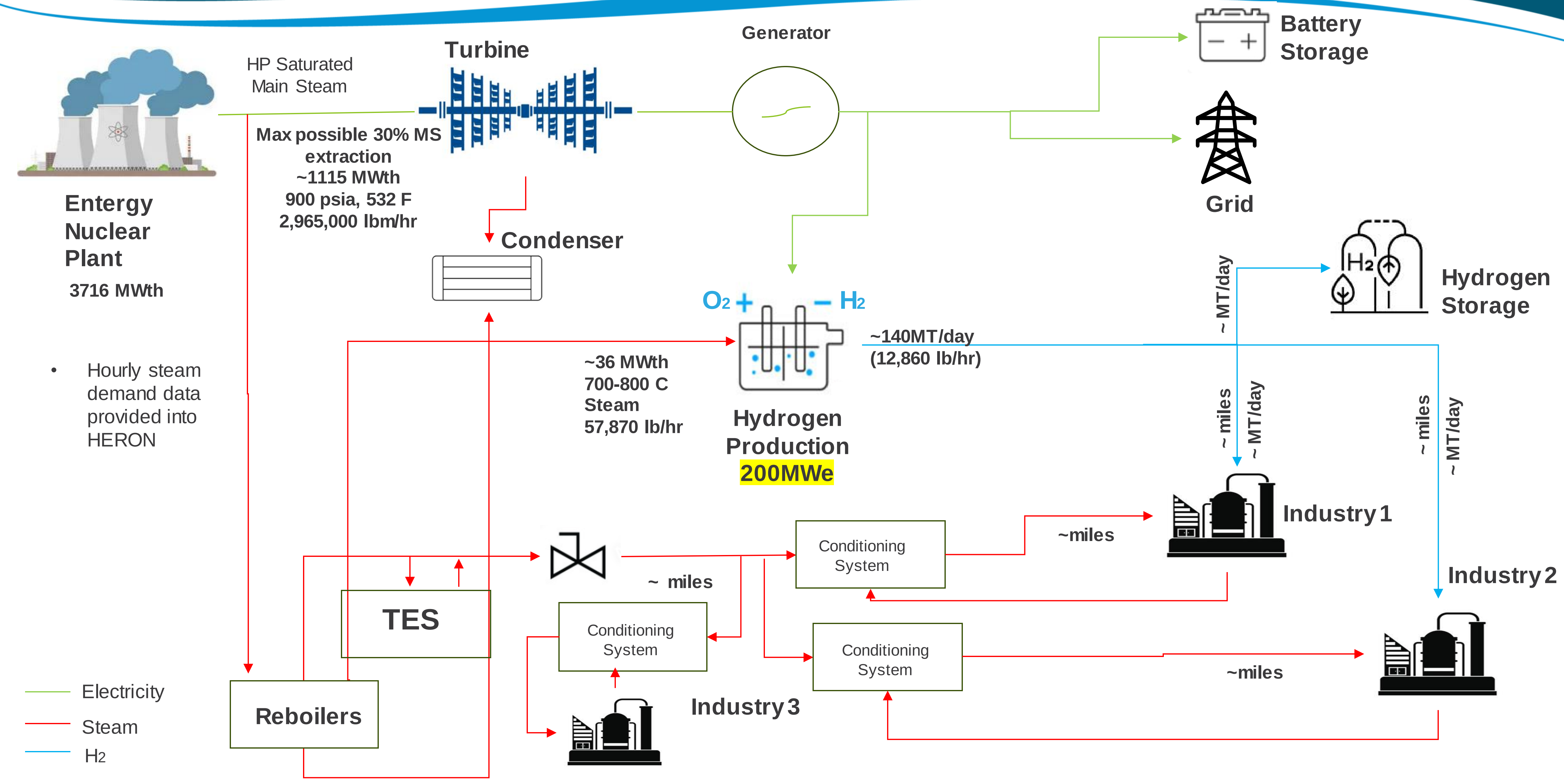


Case 1: Dynamic case providing baseload steam demand



- Hourly steam demand data provided into HERON

Case 2: dynamic case providing baseload steam demand



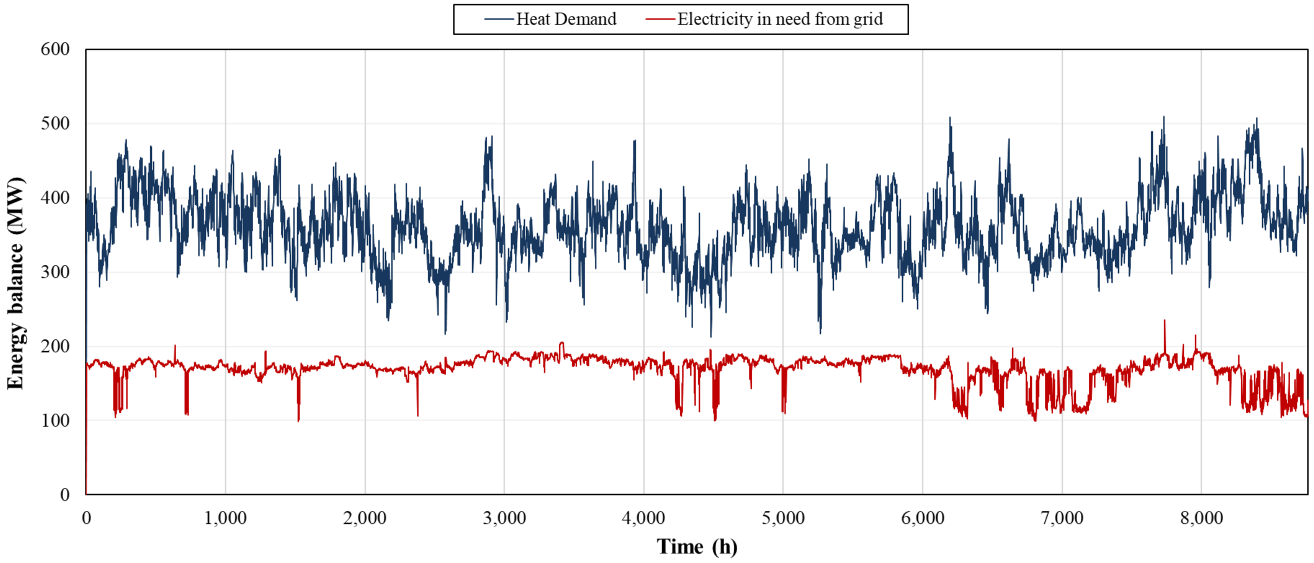
- Hourly steam demand data provided into HERON

Dow Chemical Steam Demand

- Synthetic hourly steam demand for 2022 from INL/RPT-24-78505
- Max thermal demand = **510 MW**

SCO					
Pressure Level	Average Pressure (PSIG)	Average Temperature (F)	Saturation Temp (F)	Superheat (F)	Enthalpy Available (btu/lbm)
600	604.95	719.29	489.70	229.59	1242.32
200	210.00	484.18	391.75	92.43	1138.15
75	76.75	308.32	321.00	(12.68)	1068.45

	Average Steam Demand (Mlb/hr)	Max Steam Demand (Mlb/hr)
HP	697	1,029
MP	151	433
LP	168	476



Steam Demand Profiles

Occidental Cogen Plant

- Mainly providing steam for Oxychem plant which produces ammonia, urea, and methanol.
- The Carrolton chemical plant (INL/RPT-24-78505) is located in Kentucky and produces of ethylene glycol, ethylene, and butyl rubber.
- Leverage the Dow in St. Charles demand and scale the data based on peak demand

Norco Refinery

- Energy Efficiency and Integration in the Refining and Petrochemical Industries (2016)
  - https://infoscience.epfl.ch/server/api/core/bitstreams/6026990e-1a23-4792-ab7a-9d1db7690483/content

Research status of Task 3 [Feb. 26, 2025]

- [Ongoing] Expand NIHPA to include heat/steam as part of the products
  - [Done] Additional costs of the piping per MWth
  - [Done] Additional sale price for the steam
  - [Pending] Additional costs of heat storage CAPEX and O&M
  - Mode switching design
    - Electricity sales only (BAU)
    - Hydrogen production only
    - Steam production only
    - Combinations of Hydrogen and steam generation
    - Combination of hydrogen and electricity generation
    - Combination of steam and electricity generation
    - Combination of hydrogen, steam, and electricity production

Changes made to NIHPA to include steam costs

Tool Mode Section

Energy gen. **H2 Production Only**

- H2 Production Only
- Electricity Production only
- Steam Production only
- H2&Steam
- H2&elec
- elec&steam
- H2&steam&elec

specific
and
price

3

Cost contributors for LCOH		Values in 2023	User-defined Values
Dollar Value	-	2023	2023
Hydrogen Market Price	\$/kg-H2	\$3.00	
Natural Gas Price	\$/MMBtu	\$3.00	
Electricity Sale Price	\$/MWh	\$35.00	
Steam Sale Price	\$/MWh-th	\$8.00	\$8.00
Electricity Production Costs from NPP	\$/MWh	\$30.00	\$30.00
Thermal Energy Cost from NPP	\$/kWh	\$0.01	
Utilities: Process Water Cost	\$/gal	\$0.0026242	
Utilities: Coolant Water Cost	\$/gal	\$0.0000262	

Total DCC per kW-dc (exclude integration costs)	\$/kW-dc	\$677		
Direct Capital Cost (Base)	\$ MM	\$339 M		2023
Additional DCC (Integration costs)	\$ MM	\$72 M	\$64 M	2021
Additional DCC (Steam delivery)	\$ MM	\$28 M	\$28 M	2023
Additional DCC (Storage)	\$ MM	\$ M		

Annual Variable O&M Costs	\$ M	\$139,393,648
Total Variable O&M per kW-dc	\$/kW-dc	\$3,206
HTSE: Total Electricity Cost	\$/yr	\$131,489,352
HTSE: Total Thermal Energy Cost	\$/yr	\$7,819,462
HTSE: Total Process Water Cost	\$/yr	\$369,756
HTSE: Total Coolant Water Cost	\$/yr	\$59,640
Industrial usage: remaining steam production costs	\$/yr	\$84,834
Industrial usage: remaining electricity production costs	\$/yr	\$84,646,881

Profit and Loss Statement (H2 Production Only)

	Construction	Operation	Operation	Operation	Operation
Actual Year	2029	2030	2031	2032	2033
	0	1	2	3	4
Revenue					
Source 1 (Hydrogen sales)	.0 M	357.4 M	357.4 M	357.4 M	357.4 M
Source 2 (Steam sales)					
Source 3 (Electricity sales)	.0 M	98.8 M	98.8 M	98.8 M	98.8 M
Total	.0 M	456.2 M	456.2 M	456.2 M	456.2 M
Levelized cost of Hybrid Production					
Variable O&M Cost	.0 M	139.7 M	139.7 M	139.7 M	139.7 M
Variable Operating Costs (Feedstock, Utilities)	.0 M	139.7 M	139.7 M	139.7 M	139.7 M
HTSE: Total Electricity Cost		131.5 M	131.5 M	131.5 M	131.5 M
HTSE: Total Thermal Energy Cost		7.8 M	7.8 M	7.8 M	7.8 M
HTSE: Total Process Water Cost		.4 M	.4 M	.4 M	.4 M
HTSE: Total Coolant Water Cost		.1 M	.1 M	.1 M	.1 M
Industrial usage: remaining steam production costs					
Industrial usage: remaining electricity production costs					

NPP specific inputs

Parameters	Units	Simulation Values	User-defined Values
NPP Capacity Factor	%	93.00%	
NPP Thermal Efficiency	%	34.00%	
NPP Design Capacity	MW-th	3716	
NPP power to electrolysis	MW-ac	538	
Steam to the industrial users	MW-th	1021	1021
Remaining electricity to be sold on grids	MW-ac	346	

Financial inputs			
Depreciation Type	-	MACRS	
Depreciation Period	yrs	5	5

Research status of Task 4 [Feb. 19, 2025]

- Test and run Heron Inputs on HPC
  - [Done] Install HERON and RAVEN on HPC
  - [Done] Run the input files on HPC
  - [Done] Parallel computation on HPCs
- Review the HERON inputs
  - [Done] Meeting with So-Bin to review the current HERON input
    - So-bin has run 3, 10, 20 years for HERON using dynamic electricity and shows that 300 MW is the most profitable case (Ask So-bin to present in the next meeting)
  - [Ongoing] Incorporate the following items into HERON based on the priorities
    - [Tested] NPP capacity factor of 0.93 was incorporated.
    - [Tested] H2 PTC based on IRA (The updated IRA 45V policy)
    - [Tested] Depreciation
    - [Tested] Stack degradation rates
    - [Tested] Stack replacement schedule
    - water costs (optional)
    - H2 transportation costs (optional)
- [Next Step] Run static analysis in HERON and make sure it is consistent with NIHPA

Run static analysis in HERON and make sure it is consistent with NIHPA

- Benchmarked results: Yearly cash-flow in HERON
  - CAPEX, fixed O&M, variable O&M, stack replacement schedule, revenue from electricity sales and hydrogen sales
- Ongoing work
  - Depreciation costs with the five-year depreciation
  - Steam sales and costs included in HERON and NIHPA
  - Update stack replacement schedule
    - [Existing] annual replacement with specific percentage (may not be practical)
    - [Option 1] Replace the stack every five years but increase power usage every year to consider the stack degradation for keeping the constant hydrogen production rate [Look for experimental data on this]
    - [Option 2] Replace stacks every five years but decrease the hydrogen production every year until the replacement.

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Sustaining National Nuclear Assets

lwrs.inl.gov