North Sea Transition Authority

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Bacton Energy Hub

Hydrogen Supply Special Interest Group

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SAIPEM

TotalEnergies

nationalgrid

PROGRESSIVE ENERGY

North Sea Transition Authority

NEPTUNE ENERGY

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GENESIS

Hydrogen Supply SIG – Terms of Reference

Terms of Reference (high level):

1. Review of CCS enabled and electrolyser hydrogen production technologies
2. Evaluate optimum development scenarios given an aspirational 2030 start up
3. Identify likely phasing to shift from CCS enabled to electrolytic hydrogen production
4. Estimate hydrocarbon feedstock availability for CCS enabled hydrogen production at scale at Bacton
5. Evaluate likely CCS storage options available to the BEH
6. Identify and evaluate utility service requirements (power, water etc.) required to support the project
7. Develop CAPEX and OPEX estimates for the selected development scheme and calculate LCOH for each case

Work Breakdown Structure:

1. Bacton LOF Hydrocarbon production (Total)
2. CCS enabled hydrogen production technology review (Progressive Energy)
3. Electrolytic hydrogen production technology review (Genesis)
4. Project phasing (Fluor)
5. Carbon Capture and Storage availability (Neptune/OPC)
6. BEH additional power demand (Saipem)
7. Desalination (Neptune)
8. Class 5 cost estimates (SEEL/IO Consulting)
9. Development schedule (SEEL)
10. Project Risks (SEEL)
11. LCOH (SEEL/IO Consulting)
12. Overall project management (SEEL)

BEH Vision:

Establish a sustainable hydrogen system to ensure Bacton remains a key regional Energy Hub with a low carbon future

Demand Requirement

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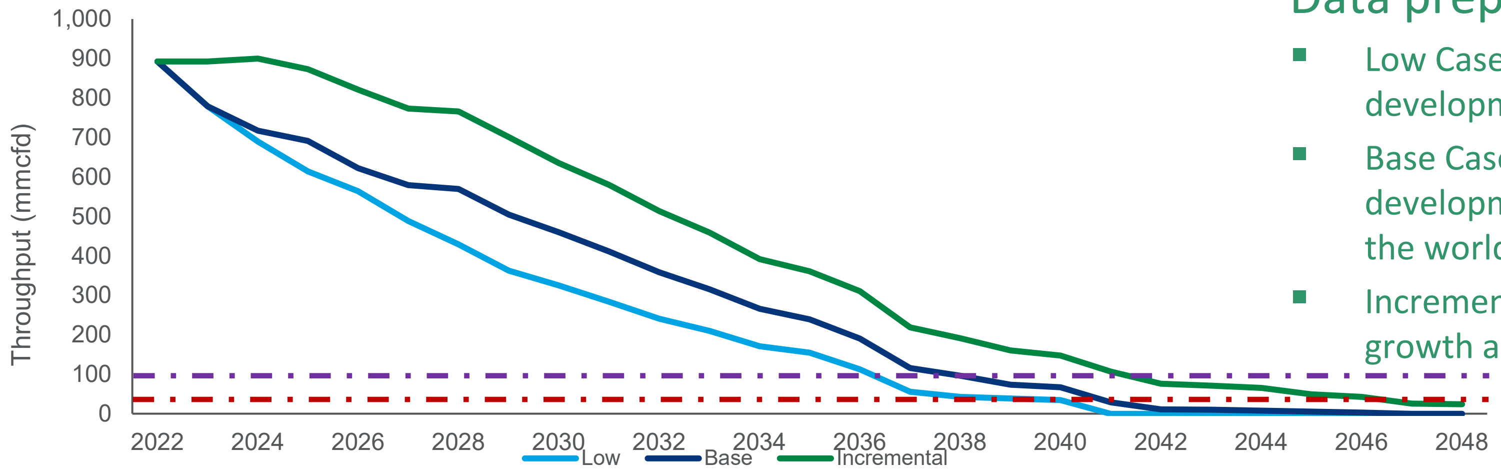
Presented in detail by JAW in Demand SIG review

Description	Core Project	Build-out
Supply Base Assumption	CCS Enabled hydrogen	CCS Enabled & Electrolytic H2
CCS Enabled & Electrolytic H2 Phasing	1 or 3 (depending upon demand) x 355MW SMR/ATR plants	2030 – 3 x 355MW SMR/ATR plants
		2040 - 3 x 355MW SMR/ATR plants 2 x 1.8GW upscaled SMR/ATR plants + 1 x 2.1 GW Electroliser
		2050 - 2 x 1.8GW upscaled SMR/ATR plants 1 x 2.1 GW Electroliser + 2 x 2.1 GW Electroliser (3 x 355MW plants retired)
Max. supply from CCS enabled hydrogen TWh & (% of demand)	1 plant - 3 TWh – (100% of demand)	2030 – 9 TWh (100%) 2040 – 39 TWh (54%) 2050 – 30 TWh (33%)
Max. supply from Electrolytic hydrogen TWh & (% of demand)	Zero	2030 – 0 TWh (0%) 2040 – 18 TWh (46%) 2050 – 54 TWh (80%)

- Base Case: 2030 1-3 (demand dependent) CCS Enabled H2 Production units
- Build out case: 2040 - Additional upscaled CCS enabled H2 production plant + at scale Electrolyser plant
- Build out case: 2050 – Upscaled CCS enable plant retained, original CCS enabled plants retired, new GW scale electrolysers installed

Anticipated Hydrocarbon LOF Production Through Bacton



Data prepared for Total by Woodmac

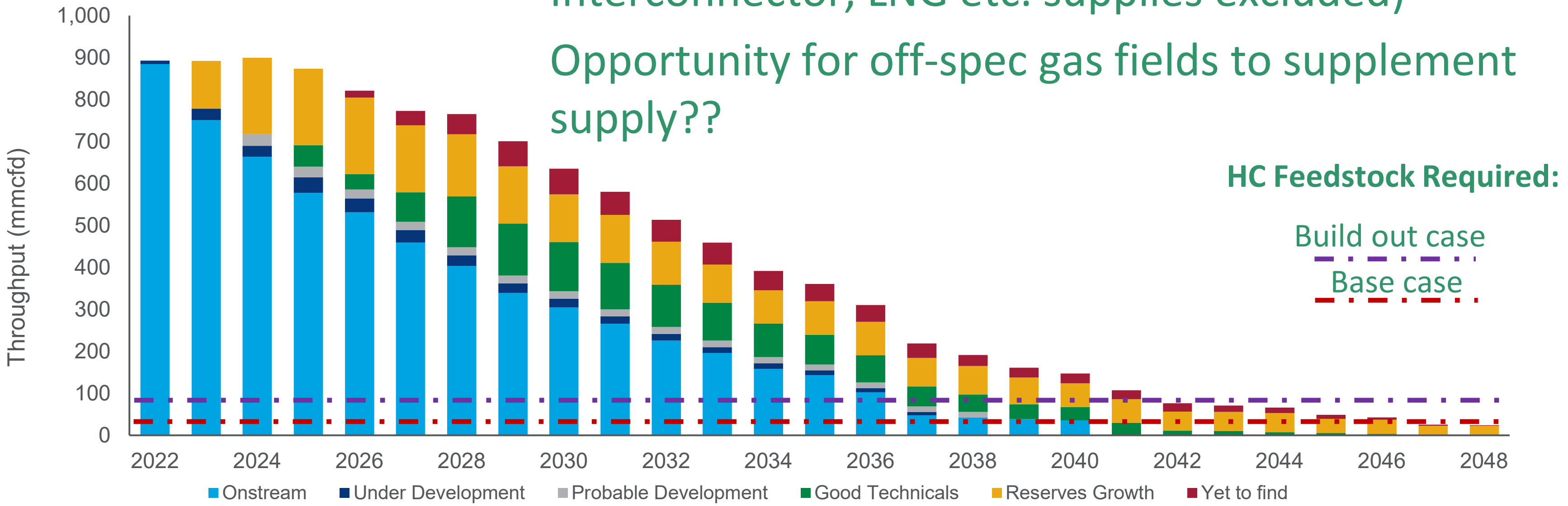
- Low Case – bare-bones look at what is onstream and under-development
- Base Case – Wood Mackenzie's base view of onstream, under-development and commercial discoveries. In an operations view of the world this would be considered a conservative view
- Incremental Case – building on the base case view we add reserves growth and YTF volumes

Profiles apply to UKCS fields only (i.e. Interconnector, LNG etc. supplies excluded)

Opportunity for off-spec gas fields to supplement supply??

Sufficient indigenous supply for base case LOF, until early 2040's for build-out case

Production deferment increasing plateau period may provide longer supply side if gas use comes under pressure due to environmental concerns (not currently likely?)



"Most likely" Incremental Case Volumes

CCS Enabled Hydrogen Production

Key Screening criteria:

Emissions: Air/Water

Cost

Safety

Efficiency

Technology

Capture Rate

Utilities: Power/Water etc.

O&M

Extensive technology screening review highlighting two leading contenders:

- Gas Heated Reformer + Autothermal Reformer
- Non-Catalytic Partial Oxidation

Both technologies are mature, have been demonstrated and optimised at scale

Broadly comparable in terms of Cost and performance

Final decision would be consortium lead based on make up of the JV, previous experience, availability etc.

Future work required to firm up costs, identify areas of potential saving and efficiencies


PROGRESSIVE ENERGY

Blue Hydrogen Production Technology Review

Report on behalf of the Bacton Energy Hub Hydrogen Supply Special Interest Group

20/09/2022

Electrolyser Hydrogen Production

All technologies listed at high level of readiness. However:

- Deployment at scale (GW++) not yet defined
  - Sizing/stacking
  - Balance of Plant requirements (emergency flare etc.)
- Large power requirement
  - Will require dedicated Green Power solution (Offshore wind, Nuclear?)
- Current cost (at scale) still prohibitive but expected to fall
- Current Supply Chain (manufacturing) capacity
- Significant water consumption requirements (see desalination)

Despite nascent deployment at scale currently, technology is expected to deliver in timeframe of BEH to predominately phase out CCS-Enabled Hydrogen (2040 onwards)

Refer to Genesis Green Hydrogen Technical Readiness Report

	Alkaline	PEM	SOEC	AEM[2]
Efficiency	70-75% (Typical)	70-75% (Typical), 75% (Siemens)	90% (Haldor), 90%+ (Bloom)	88% (Hydrolite)
TRL	9	9	7	7
Start Time (Warm/Cold)	5 min / 60 min (Typical)	30s / 5min (Plug)	6min / 15hr (Bloom)	"Fast" (Hydrolite)
Operational Flexibility	40-100% (Cummins)	10-100% (Siemens) 5-125% (Cummins)	10-100% (H-T)	"Good" (Hydrolite)
Product Pressure	30barg (Cockerill) 30barg (McPhy) Atm (Thyssenkrupp, Nel)	20-30barg (ITM) 40barg (Plug)	Atm (Bloom) 2barg (H-T)	35barg (Enapter)
Lifetime / Stack Replacement	10yr (Sunfire)	10yr (Siemens)	5yr (Bloom)	10yr (Hydrolite)
Purity	99.8 (Cockerill) 99.99 (after drying)	99.999 (ITM), 99.999 (Plug)	99.99 (after drying)	99.999 (Hydrolite)
Capital Cost ($/kW)	Moderate	High	High	Low Claimed (Hydrolite)
Feedwater Quality Requirement	Flexible	High	High	Flexible
Size / Weight	45m^2/MW	25-30m^2/MW	~45m^2/MW	Note 1

Notes:

1. Insufficient information exists in the public domain to provide more detailed view;
2. Few instances of AEM's being used beyond pilot scale applications and therefore many of these assessments are claimed by the manufacturers rather than demonstrated at scale.
3. In general, publicly available data can vary. The table above is a guide only.

Carbon Capture and Storage (CCS)

Scope:

Initially 1-5 MTPA (dependent upon scenario)

Re-use of existing infrastructure (well/Pipeline/Platforms where possible (See Infrastructure SIG Presentation)

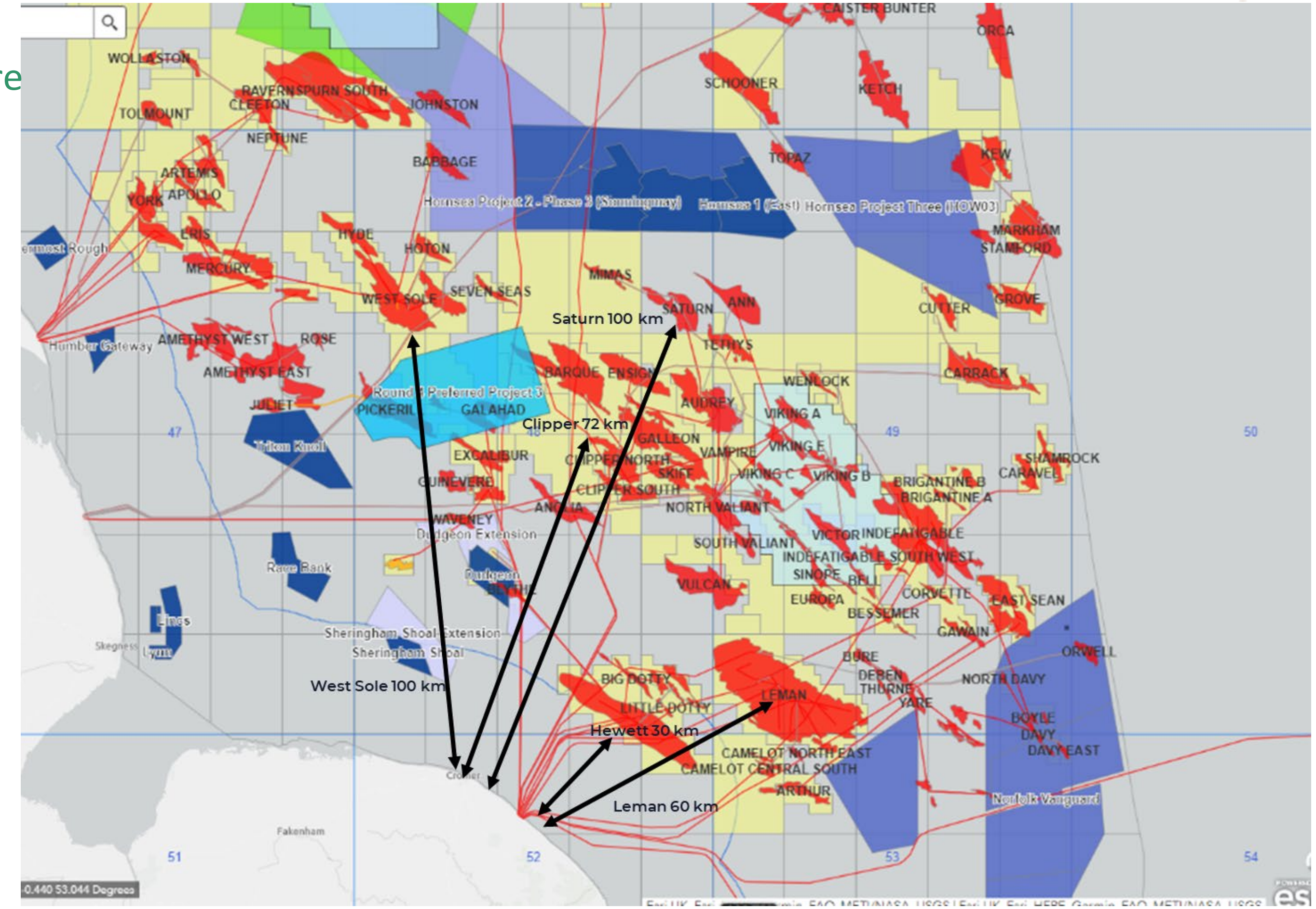
Use of depleted gas fields prioritised (aquafers also possible)

Phase ambivalent at present

Field relinquishment compatible with BEH timing (available 2030)

Numerous fields identified:

- Hewett
- Leman
- Indie
- Clipper
- Saturn
- West Sole
- Sean



Note:

Scoping performed PRIOR to NSTA 1st CCS licencing round

Utilities Power and Water

TOTAL ELECTRICAL DEMAND (Mwe)					90
COD	PROCESS	SUB-PROCESS	PLANT	NAMEPLATE	Demand [Mwe]
2030	CCS enabled H2	Production & CCS	CCS enabled Plant 1	355 MWth	28
			CCS enabled Plant 2	355 MWth	28
			CCS enabled Plant 3	355 MWth	28
		Desalination	SWRO PLANT 1	45 m^3/h	0.20
			SWRO PLANT 2	45 m^3/h	0.20
			SWRO PLANT 3	45 m^3/h	0.20

2030 – Both scenarios feasible using NG (upgrading Earlham Grid Substation feeder)

2040/50 scenarios would require significant infrastructure upgrades not currently planned – Dedicated sustainable energy source required – Wind/Solar/Nuclear etc. with grid stabilisation

Water Requirement:

Parameters	Core Project 2030	Build out		
		2030	2040	2050
H_2O input required (m^3/hr)	45	135	1,527	3,264
Seawater intake (m^3/hr)	126	378	4,277	9,140
Electricity requirement (kW)	198	594	6,720	14,363
Capacity (m^3/day)	1,080	3,240	36,656	78,344
Typical Plant footprint (m^2)	1,233	2,124	19,729	27,066
Water Storage (m^3)	1,080	3,240	36,656	78,344
Water Storage Footprint (m^2)	150	300	2,000	4,000

TOTAL ELECTRICAL DEMAND (Mwe)					6600
COD	PROCESS	SUB-PROCESS	PLANT	NAMEPLATE	Demand [Mwe]
2030	CCS enabled H2	Production & CCS	CCS enabled Plant 1	355 MWth	*0 (RETIRED)*
			CCS enabled Plant 2	355 MWth	*0 (RETIRED)*
			CCS enabled Plant 3	355 MWth	*0 (RETIRED)*
		Desalination	SWRO PLANT 1	45 m^3/h	*0 (RETIRED)*
			SWRO PLANT 2	45 m^3/h	*0 (RETIRED)*
			SWRO PLANT 3	45 m^3/h	*0 (RETIRED)*
COD	PROCESS	SUB-PROCESS	PLANT	NAMEPLATE	Demand [Mwe]
2040	CCS enabled H2	Production & CCS	CCS enabled Plant 4	1800	141
			CCS enabled Plant 5	1800	141
		Desalination	SWRO PLANT 4	228 m^3/h	1.0
			SWRO PLANT 5	228 m^3/h	1.0
	Electrolytic H2	Production	ALKALINE ELECTROLYSER 1	2100 Mwe	2100
		Desalination	SWRO PLANT 6	378 m^3/h	1.7
COD	PROCESS	SUB-PROCESS	PLANT	NAMEPLATE	Demand [Mwe]
2050	Electrolytic H2	Production	ALKALINE ELECTROLYSER 2	2100 Mwe	2100
			ALKALINE ELECTROLYSER 3	2100 Mwe	2100
		Desalination	SWRO PLANT 7	378 m^3/h	1.7
			SWRO PLANT 8	378 m^3/h	1.7

Project High Level Risk Register

Risk/Description	Risk Pre-Mitigation	Possible Mitigation	Risk Post-Mitigation
CCS Enabled Hydrocarbon Production			
Lack of domestic supply		Further review of reserves estimates. Option to use imported gas via Interconnectors. Earlier electrolytic hydrogen	
High gas price		Government (CFD) support likely required. Consider dedicated supply option.	
Facilities footprint exceeds available space		Further work required particularly for build-out phases. Commence consents/planning process early.	
Electrolytic Hydrogen Production			
TRL for production at scale is too late for BEH		Current pace of technical development is focused on production at scale	
Facilities footprint could exceed available space		Further work required particularly for build-out phases. Commence consents/planning process early. Assess offshore option.	
OWF power supply intermittent, back up required		CCS Enabled hydrogen, hydrogen storage & grid connected power supply offer potential solutions	
Construction & Schedule			
Complex construction adjacent to operational facilities (SIMOPs)		Similar construction projects at COMAH sites have been successfully executed before	
Phasing of CCS Enabled & electrolytic hydrogen mismatched with demand requirements.		Demand requires continual assessment up to FID and beyond. Early contractual commitments.	
Supply chain constraints particularly with electrolytic hydrogen supply chain causes delays		Early engagement/assessments & detailed planning. Possible early commitments with key suppliers.	

Key Risk Areas:

Costs – particularly variable OPEX (Feedstock, power)

Space constraints – Base case ok, electolyser plants are large

Power – Significant requirement for build out case

Demand – Market yet to be established. Blending is a key decision

CCS			
Lack of suitable sites delays CCS Enabled hydrogen development		CCS progress to be monitored closely for alignment with BEH. Recent licensing round appears encouraging	
Cost to access CCS infrastructure is too high		SNS offers good CCS opportunity. CCS is a Gvt/industry commitment & will require an 'acceptable' commercial model. BEH could access a larger regional CCS scheme.	
Power Supply			
Inadequate local grid connection capacity for BEH facilities		Supply for initial CCS enabled hydrogen requirements appears possible. Evaluate alternatives (grid upgrade, renewables etc)	
Desalination Facilities			
Brine discharge & dispersal		Use of existing pipelines for distant offshore disposal, blending, etc	
Facilities footprint & location		Further work required particularly for build-out phases. Commence consents/planning process early.	
General			
Project economics are a challenge		Detailed modelling & facilities optimisation. Gvt incentives. Macro pressure to make energy transition successful, Gvy CfD arrtangements for the hydrogen economy	
Insufficient demand for hydrogen		Detailed demand modelling. Focus on key consumers ie power stations. Gvt incentivisation and blending into the grid	
Delays in regulatory processes adversely impacts schedule		Early applications & stakeholder engagement. Energy transition a national priority	
Public perception/relations issues and resistance to BEH especially blue hydrogen development		Stakeholder engagement & PR process. CCS Enabled hydrogen an enabler for energy transition	
Possibility of CCS & BEH competing for same land/space		Future co-ordinated & detailed assessment with Gvt support following recent CCS licensing applications	

Project Schedule (To Start Up)

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Gated process

Planning & permitting

FID

Stage gate process

	0	1	2	3	4	5	6	
	Launch	Identify & Initiate including options	Pre- FEED	Define & Plan FEED	Execute Design, Build & Commissioning	Completion & Commissioning (handover to operations)	Beneficial Operational trials	COD
Scenario 1 optimistic	2022 to Qtr 2 2023		Qtr. 2 2023 to Qtr. 4 2023 6 months	Qtr. 1 2024 - Qtr. 4 2024 12 months	Qtr. 1 2025 to Qtr. 1 2028 36 months		Qtr. 2 2028 3 months	Mid 2028
Scenario 2 pessimistic	2022 to Qtr. 2 2024		Qtr. 1 2025 - Qtr. 4 2025 12 months	Qtr. 1 2026 to Qtr. 2 2027 15 months	Qtr. 2 2027 to Qtr. 2 2032 60 months		Qtr. 3 & 4 2032 6 months	Start 2033
Scenario 3 target	2022 to Qtr. 2 2023		Qtr. 3 2023 - Qtr. 1 2024 9 months	Qtr. 2 2024 - Qtr. 2 2025 12 months	Qtr. 3 2025 to Qtr. 1 2029 40 months		Qtr. 2 & 3 2029 6 months	Qtr. 3 2029

DCO or TCPA will also drive timeline if needed for FID

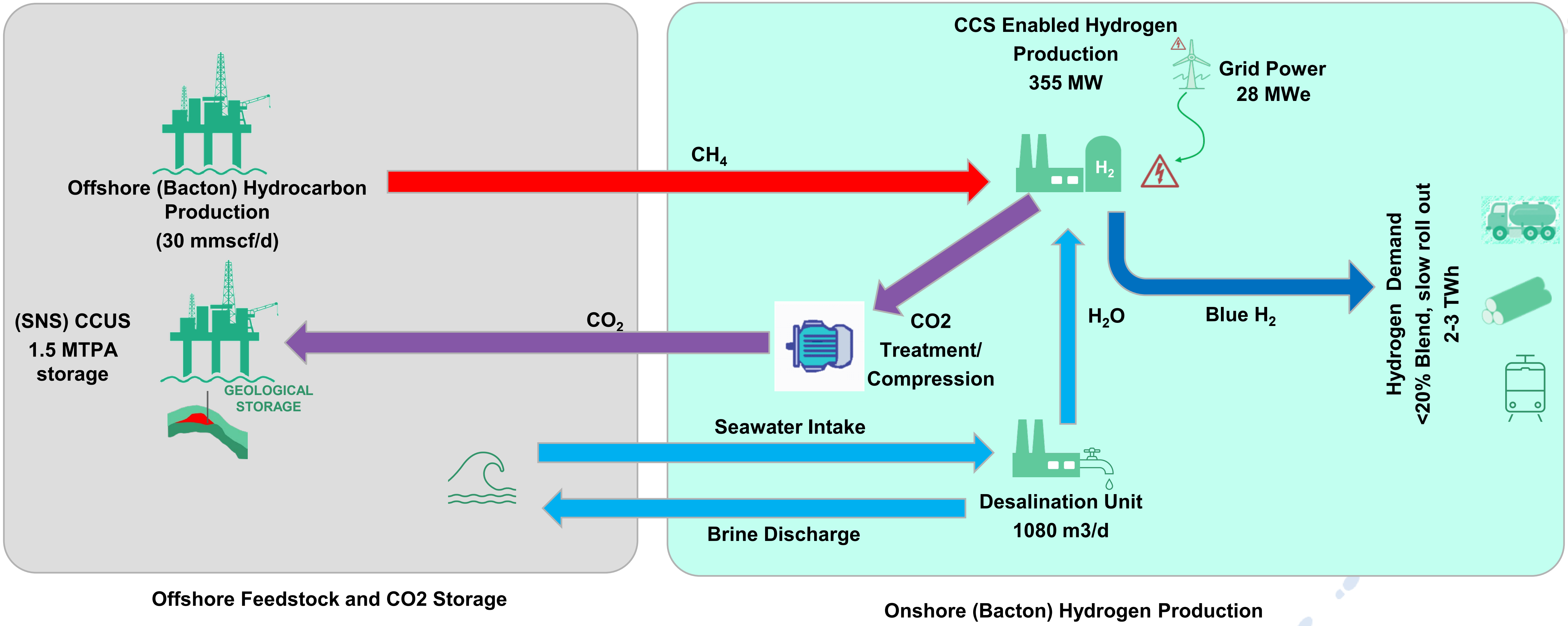
Engagement of consultants & Engineering contractors

General supply chain awareness, events & engagement

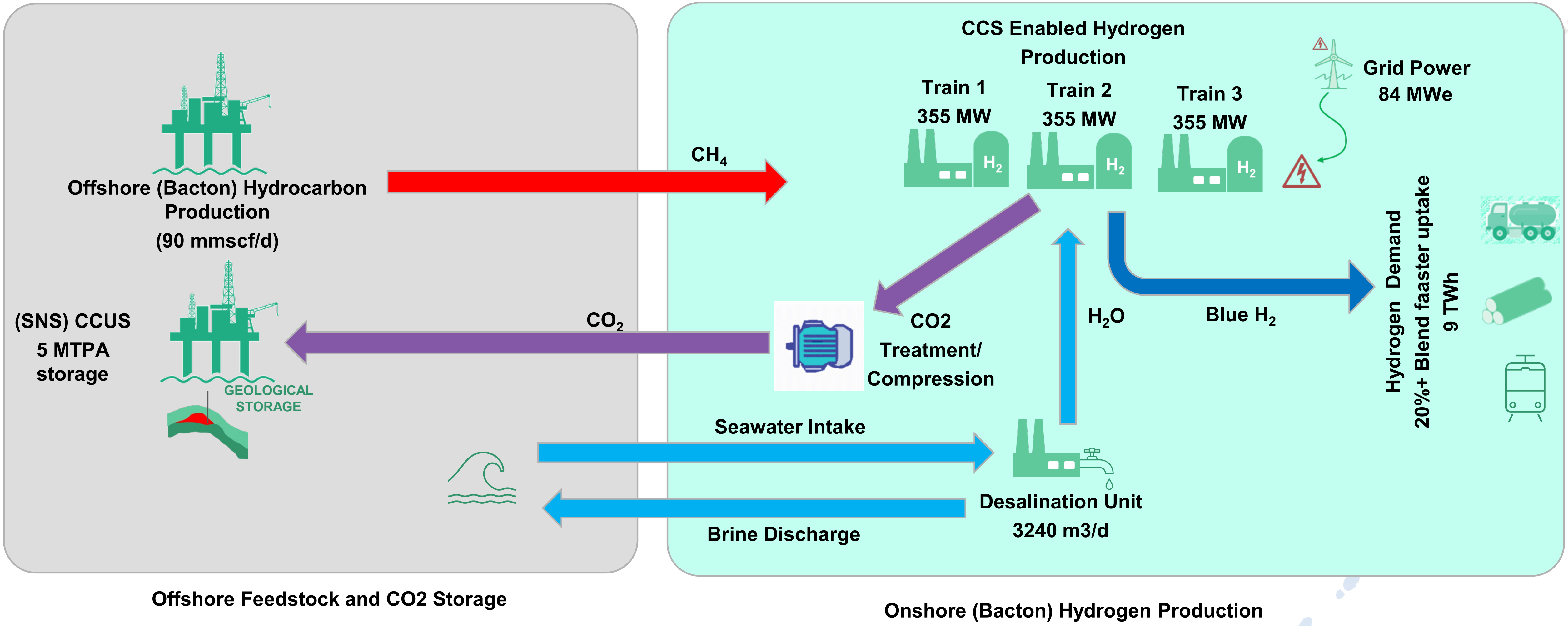
Engagement with Technology solution providers

Engage with good & service providers including construction companies

Bacton Energy Hub – 2030 Core Project



Bacton Energy Hub – 2030 Build Out Case Project



Bacton Energy Hub – 2050 Build Out Case Project