INTRODUCTION TO ABB BALANCE OF OPERATIONS

A Fully Integrated Approach for CCS Cluster Projects Balance of Operations – Digital Solutions for CCS

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ABB Balance of Operations

The major challenge facing CCS industrial hub projects is the transition from design to operations

ABB Balance of Operations is a full chain model of the entire CCS network, from emitter to disposal reservoir, to support operators and operations

Maximize uptime by always operating where the system can react to change

Assure safety by avoiding corrosion, temperature, and integrity limits

Save money by reducing compression, heating, and other operating costs

ABB are the experts
in process/safety operations

Pace CCS are the experts
in CCS design

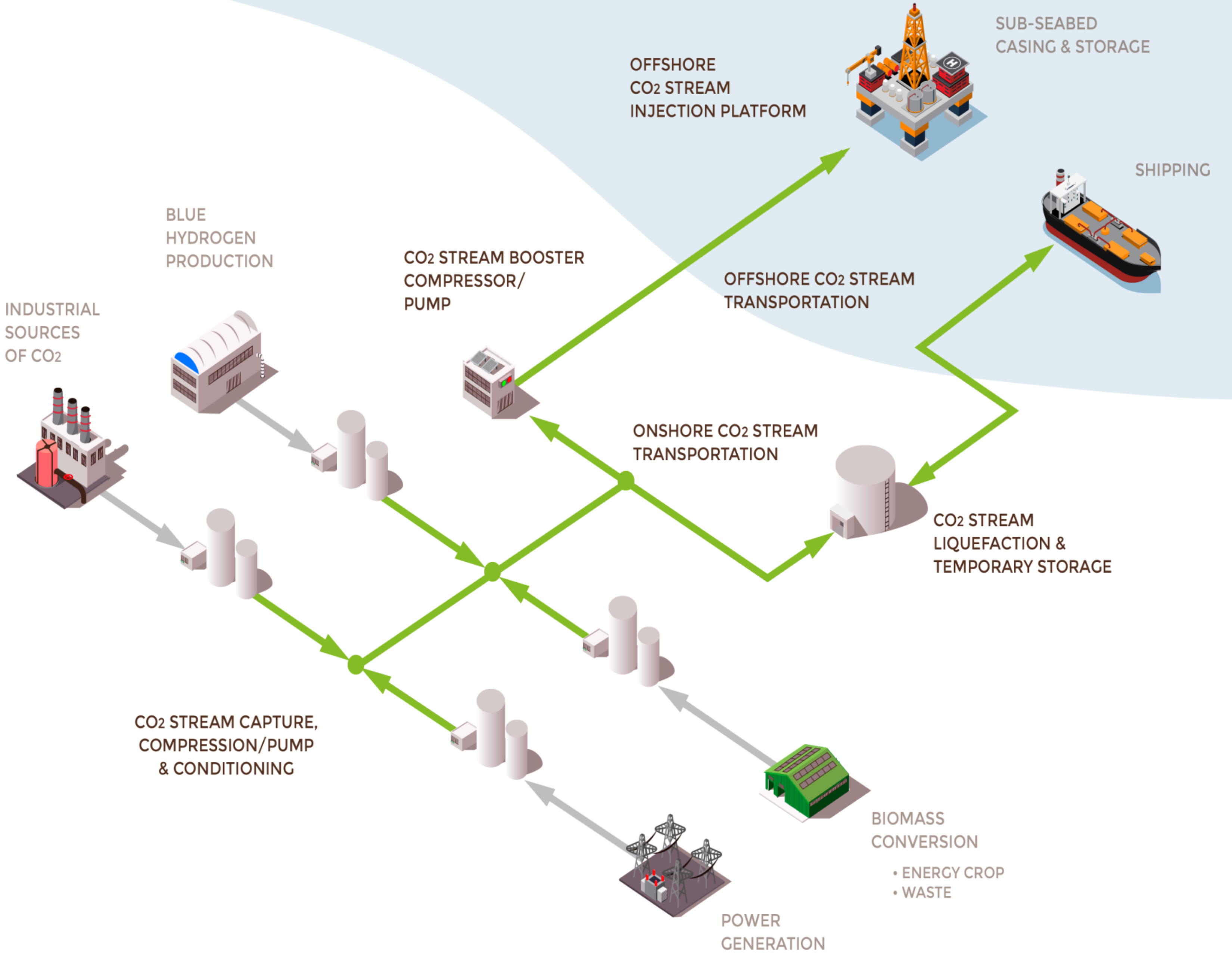
Example of a CCS Cluster

Investment is phased as the cluster grows:

- Gathering pipeline network
- Export pipelines
- Power
- Compression
- Blue hydrogen & new industry
- Storage reservoirs
- Wells & injection capacity

Re-use of infrastructure:

- Midstream and oil & gas pipelines
- Re-purposed platforms
- Re-purposed wells



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Carbon Capture & Storage (CCS)

CCS – A new challenge

- CO_2 emissions contain impurities
- Impurities can react to create corrosive compounds
- We need to protect the overall CCS infrastructure
  - Pipelines
  - Compressors
  - Valves / Wellheads
  - Aquifer / reservoir

- CO^2 states vary from Gaseous to Supercritical
- Minimize Costs – Maximize storage capacity safely
- It is most cost effective to use existing infrastructure where possible

Figure: carbon steel corrosion in CO_2, caused by typical CCS impurities reacting to form strong acids

- 100 bar / 1500 psi & ambient temperature
- 99+ % CO_2
- Impurities are NO_x & H_2O at <100 ppm (0.01%)

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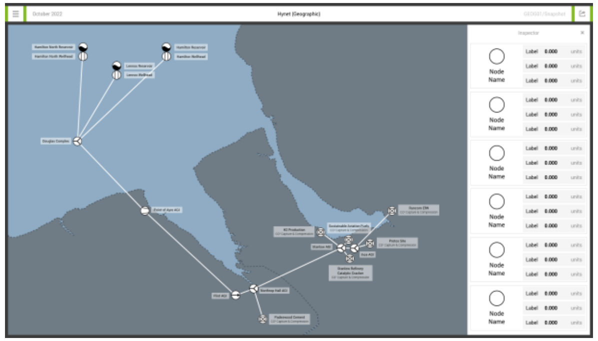
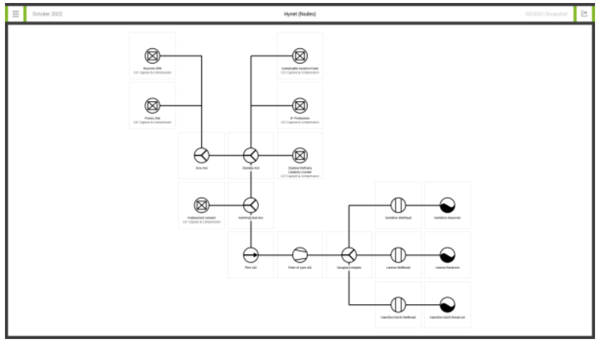
CCS Chain

- Analyze each emitters composition
- Calculate the blended emission composition
- Predict corrosion factors
- Model the reservoir / aquifer
- Minimize energy consumption for compression and heating when required
- Learn how parameters change over time (machine learning)
- Factor all the above into a holistic Digital Tool set
- Assure availability as emitters go online/offline
- Reduce operating costs and energy consumption
- Maximize storage capacity
- Perform “what if” scenario modelling
- Enable autonomous operations

Digital Twin





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OPTIMAX® CCS MVP

Industrial Decarbonization

- Improve Availability and Efficiency
- Full Lifecycle, Planning & Operations
  - Planning: Detailed simulation
  - Operation: Predictive- and Realtime optimization for injection and compression
- Remote, autonomous operation
- Model consists of
  - Carbon Emitters
  - Compressors
  - Heating and Cooling
  - Wells (e.g. reservoir injection)

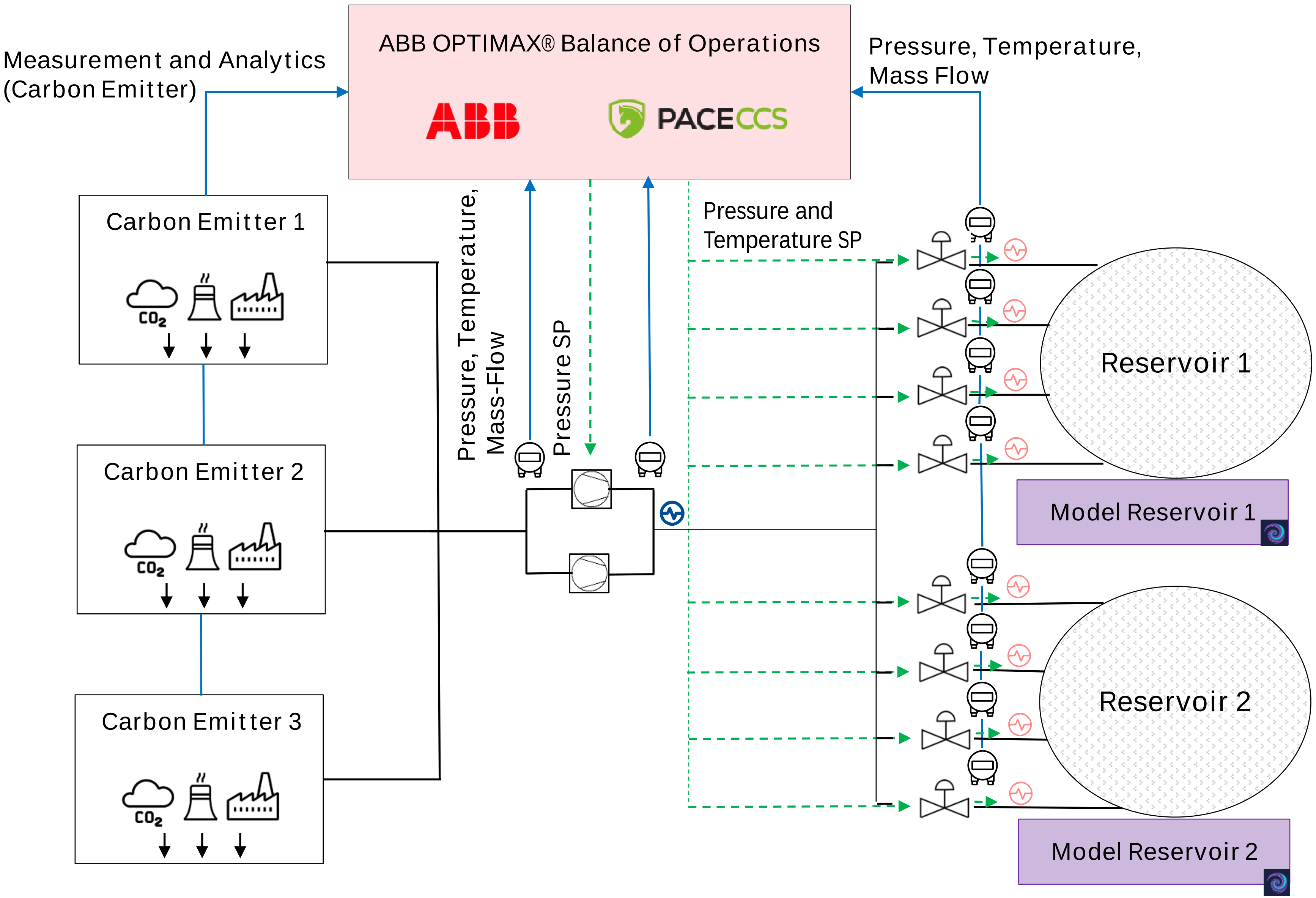


ABB Balance of Operations
Typical Overview

Map | Status | Forecast | Transmitters

Balogun Reservoir (#6)

		Inlet	Outlet	Outlet	Bottomhole
From/To		Port Compressor	Heater	Choke	Reservoir
Vapour Fraction	-	1.0	1.0	1.0	1.0
Temperature	°C	17.0	30.0	29.0	29.0
Pressure	bara	25.0	25.0	32.0	32.0
Mass Flowrate	MTPA	3.0	3.0	2.3	2.3
Volumetric Flowrate	m3/h	6279.9	6747.9	3817.1	3817.1
Properties					
Molar Enthalpy	kJ/kmol	7568.4	8159.8	7751.3	7751.3
Molecular Weight		43.9	43.9	43.9	43.9
Mass Density	kg/m3	54.5	50.8	68.9	68.9
Viscosity	Pa.s	1.57E-05	1.62E-05	1.65E-05	1.65E-05
Molar Volume	m3/kmol	0.805	0.865	1.466	1.120
Compressibility	-	0.838	0.861	0.908	0.891
Composition (mole fraction)					
Water		0.000050	0.000050	0.000050	0.000050
Methanol		0.000000	0.000000	0.000000	0.000000
Carbon Dioxide		0.997750	0.994523	0.995701	0.995701
Hydrogen		0.002200	0.001023	0.000733	0.000733
Benzene		0.000000	0.000000	0.000002	0.000002
Methane		0.000000	0.000000	0.000000	0.000000
Carbon Monoxide		0.000000	0.000005	0.000287	0.000287
Argon		0.000000	0.000000	0.000028	0.000028
Nitrogen		0.000000	0.004361	0.003127	0.003127
Oxygen		0.000000	0.000005	0.000004	0.000004
Hydrogen Sulphine		0.000000	0.000000	0.000000	0.000000
Sulphur Dioxide		0.000000	0.000016	0.000020	0.000020
Nitric Oxide		0.000000	0.000014	0.000019	0.000019
Nitrogen Dioxide		0.000000	0.000002	0.000001	0.000001
Ethanol		0.000000	0.000000	0.000000	0.000000
Ammonia		0.000000	0.000000	0.000000	0.000000
Hydrogen Chloride		0.000000	0.000000	0.000018	0.000018
Chlorine		0.000000	0.000000	0.000008	0.000008

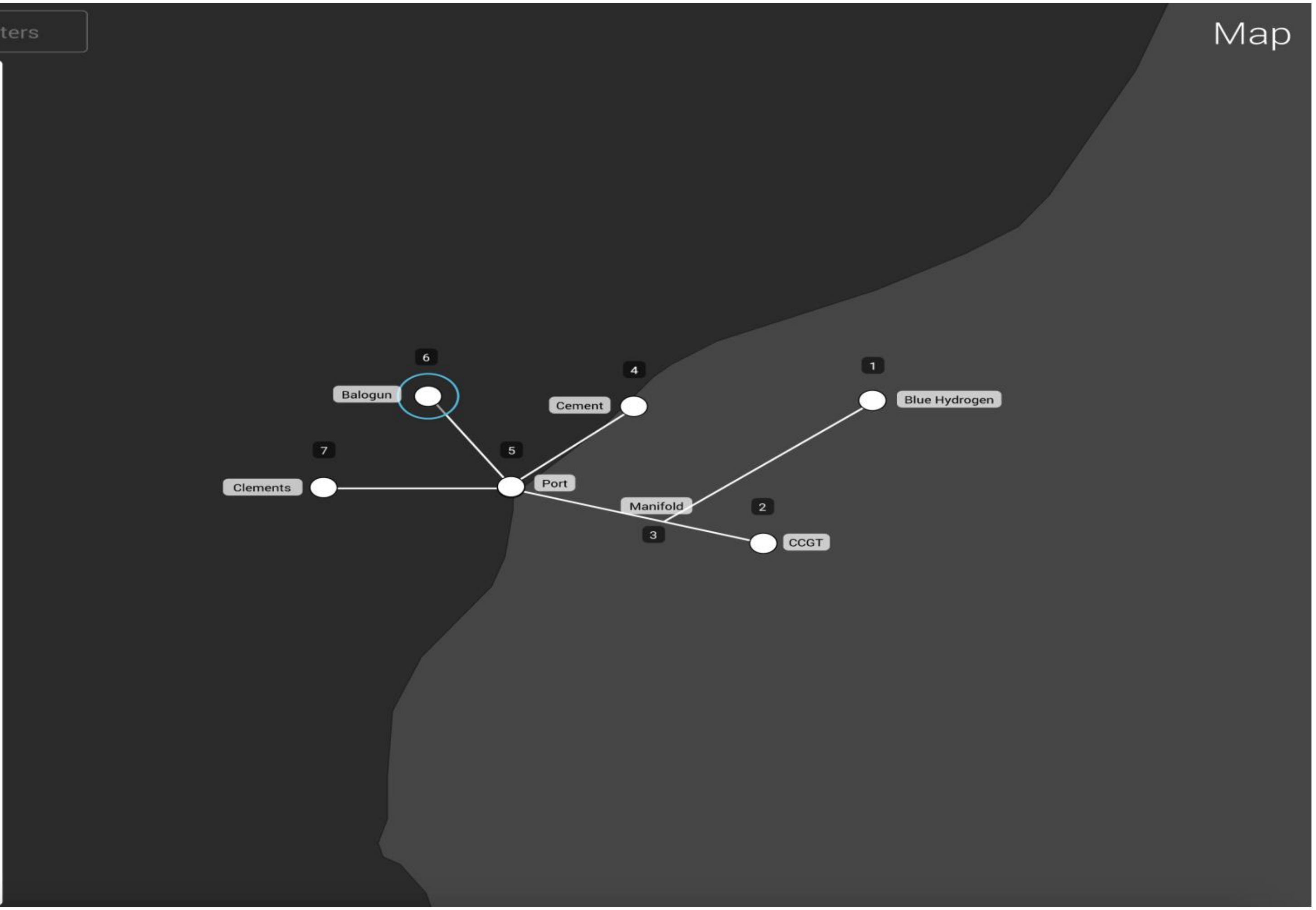


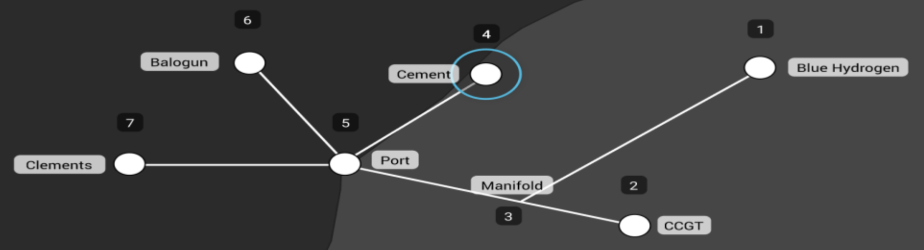
ABB Balance of Operations
Asset Status

Map | **Status** | Forecast | Transmitters

Status

Cement Emitter (#4)

Vapour Fraction	-	1.0
Temperature	°C	55.0
Pressure	bara	35.0
Mass Flowrate	MTPA	1.7
Volumetric Flowrate	m3/h	2909.5
Properties		
Molar Enthalpy	kJ/kmol	8848.0
Molecular Weight		44.0
Mass Density	kg/m3	66.7
Viscosity	Pa.s	1.76E-05
Molar Volume	m3/kmol	0.660
Compressibility	-	0.850
Composition (mole fraction)		
Water		0.000050
Methanol		0.000000
Carbon Dioxide		0.998687
Hydrogen		0.000000
Benzene		0.000008
Methane		0.000000
Carbon Monoxide		0.001000
Argon		0.000100
Nitrogen		0.000000
Oxygen		0.000000
Hydrogen Sulphine		0.000000
Sulphur Dioxide		0.000030
Nitric Oxide		0.000030
Nitrogen Dioxide		0.000000
Ethanol		0.000000
Ammonia		0.000000
Hydrogen Chloride		0.000065
Chlorine		0.000030



Name	Blue Hydrogen	CCGT		Cement	Port	Balogun Tophole	Clements Tophole
Type	Emitter	Emitter	Manifold	Emitter	Compressor	Reservoir	Reservoir
Number	1	2	3	4	5	6	7
Vapour Fraction [-]	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Temperature [°C]	55.0	55.0	29.0	55.0	40.0	18.6	20.4
Pressure [bara]	35.0	35.0	32.0	35.0	35.0	15.0	15.0
Mass Flowrate [MTPA]	2.0	2.3	4.3	1.7	6.0	3.0	3.0
Volumetric Flowrate [m3/h]	3431.0	3954.8	7127.3	2909.5	9485.6	421.5	421.5
CO2 content (mol fraction)	0.997750	0.991720	0.994523	0.998687	0.995701	0.995701	0.995701
	SHOW	SHOW	SHOW	SHOW	SHOW	SHOW	SHOW

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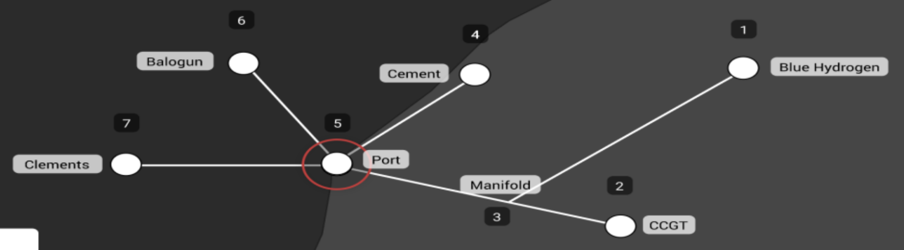
Forecast Predictions

Map | Status | Forecast 3 | Transmitters

Forecast

Port Compressor (#5)		Outlet Cooler	Outlet Balogun	Outlet Clements
From/To				
Vapour Fraction	-	1.0	1.0	1.0
Temperature	°C	50.1	50.1	50.1
Pressure	bara	35.0	35.0	35.0
Mass Flowrate	MTPA	6.0	3.0	3.0
Volumetric Flowrate	m3/h	9485.6	4742.8	4742.8



Scenarios

	ALARM	TRIP	OP. LIMIT	
Weather Change	YES	YES	YES	SHOW
Blue Hydrogen emitter goes offline	NO	NO	NO	SHOW
CCGT emitter goes offline	NO	NO	NO	SHOW
Cement emitter goes offline	NO	NO	NO	SHOW
Emitter comes online				SHOW
Cement emitter kiln changeover	NO	NO	NO	SHOW
Well changeover: Balogun	NO	NO	NO	SHOW
Well changeover: Clements	NO	NO	NO	SHOW
Heating failure: Balogun	NO	NO	NO	SHOW
Heating failure: Clements	NO	NO	NO	SHOW

Event Log

```
11:24 OPERATIONAL LIMIT "Weather change" (0 minutes ago)
11:24 TRIP "Weather change" (0 minutes ago)
11:24 ALARM "Weather change" (0 minutes ago)
11:24 All scenario checks complete (0 minutes ago)
11:00 1 ALARM scenario predicted in last hour (24 minutes ago)
11:00 No TRIP scenarios predicted in last hour (24 minutes ago)
11:00 No OPERATIONAL LIMIT scenarios predicted in last hour (24 minutes ago)
10:14 End ALARM "Cement emitter kiln changeover" (70 minutes ago)
10:00 1 ALARM scenario predicted in last hour (84 minutes ago)
10:00 No TRIP scenarios predicted in last hour (84 minutes ago)
10:00 No OPERATIONAL LIMIT scenarios predicted in last hour (84 minutes ago)
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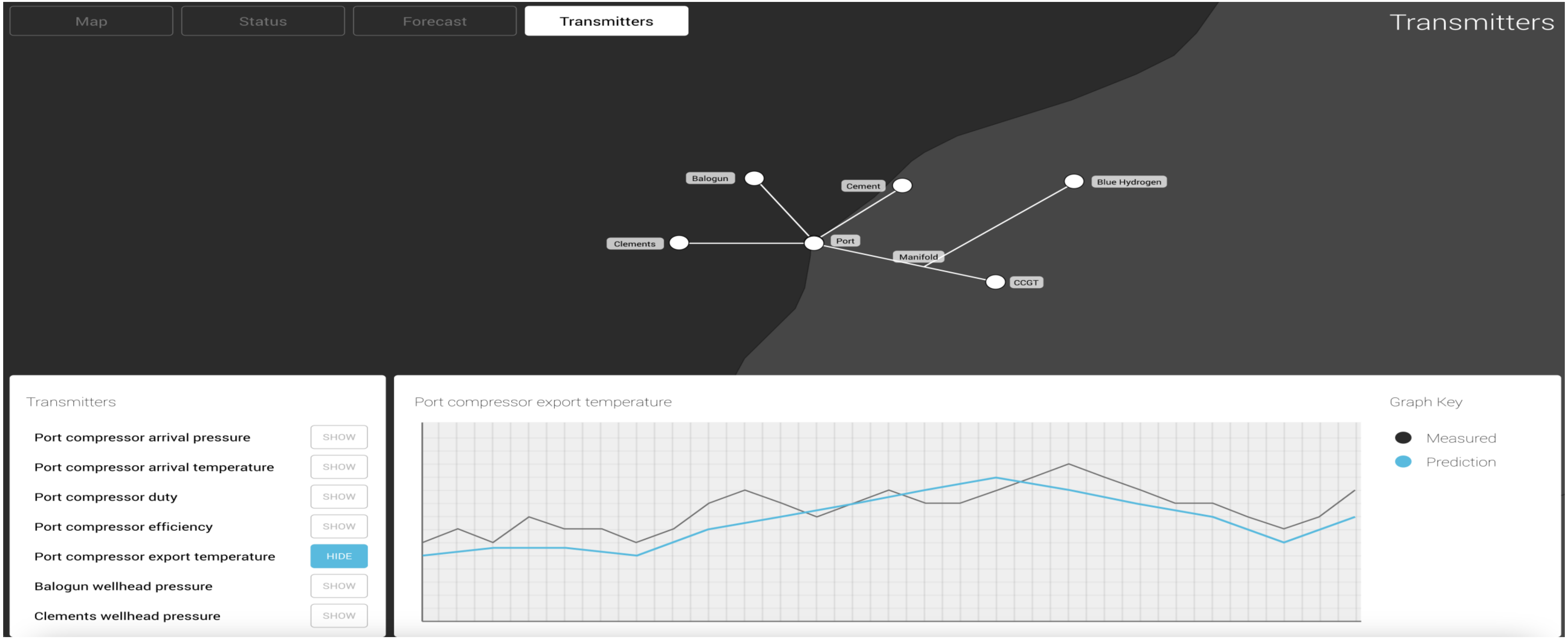
PV Comparisons



Business Risks & Opportunities

Operation Issue	Operational Effect	Consequences	Would BoPs mitigate those consequences
Emitter plant trips	Lower flow rates of CO_2 change and altered blended composition	Revised set points required, compression, pressure, temperature	Yes
Pipeline integrity breach or compressor trip	Unable to collect and transport CO_2	Liquidated damages applied from emitters	Yes
Sub-surface geological formation unavailable	CCS network shutdown	Liquidated damages applied from emitters	Yes
Corrosion	Integrity of infrastructure	Shutdown and high expense to repair. LDs from emitters	Yes
Energy usage, compression and heating	Excess OPEX costs	Profitability	Yes
Sub-surface geological formation	Reduced capacity and life expectancy	Failure to meet design life/performace criteria	Yes
New emitters coming on-line	Increased flow rates of CO_2 change and altered blended composition	Modification to compression, heating and instrument sizing	Yes
Not having a holistic operational view of the complete CCS chain	Inefficient operations, higher OPEX costs, risks to availability	Various shutdown scenario's	Yes

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