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Technical and Economic Feasibility of Remote Area Hydrocarbon Exploitation Using a Clean Energy Producing Vessel

by

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‘On the Technical and Economic Feasibility of Remote Area Hydrocarbon Exploitation Using a Clean Energy Producing Vessel’

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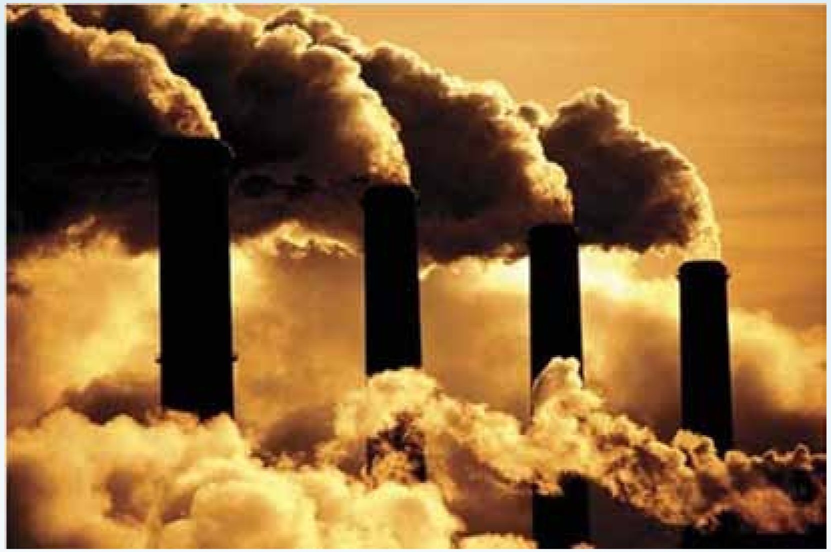
Lecture Format

- Energy and Emissions
- The CEPV Concept
  - Prime-mover Options
  - Gas Flows and Separation
  - Electrical Power Transmission Schemes
  - CO_2 Capture and Sequestration
  - Economic Analysis
  - Case Studies
- Conclusions

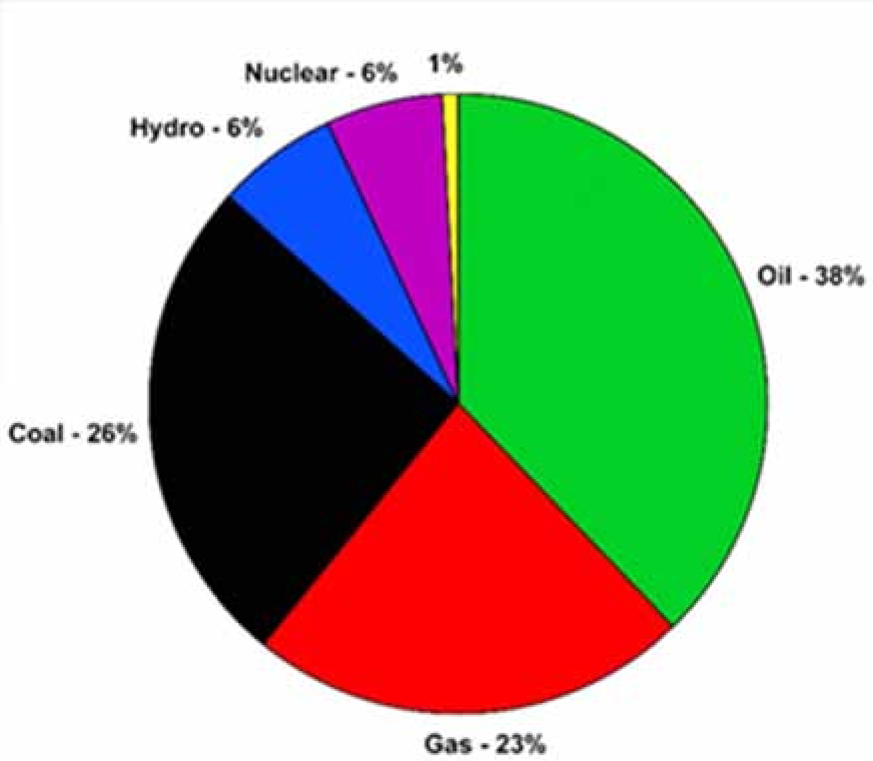
ENERGY AND EMISSIONS

Energy and Greenhouse Gases






Worldwide Energy Supply Today

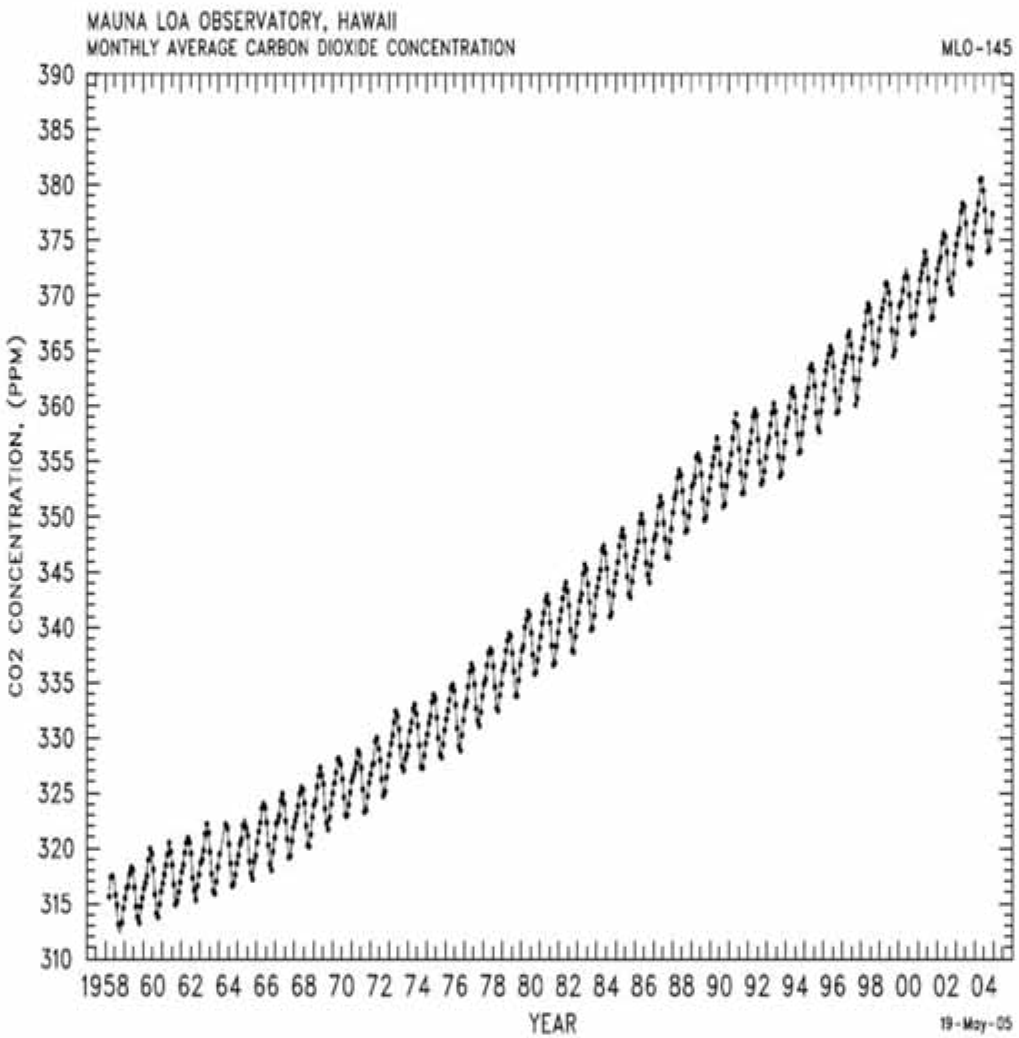


Source: IEA

- Hydrocarbons (oil, gas and coal) supply 87% of our energy needs.
- Nuclear Fission supplies only 6% of our energy needs.
- Renewables supply only 7% of our energy needs and is predominantly large scale hydro-electric schemes.

Today the world uses nearly twice as much energy as it did 30 years ago!

World CO2 Emissions Today

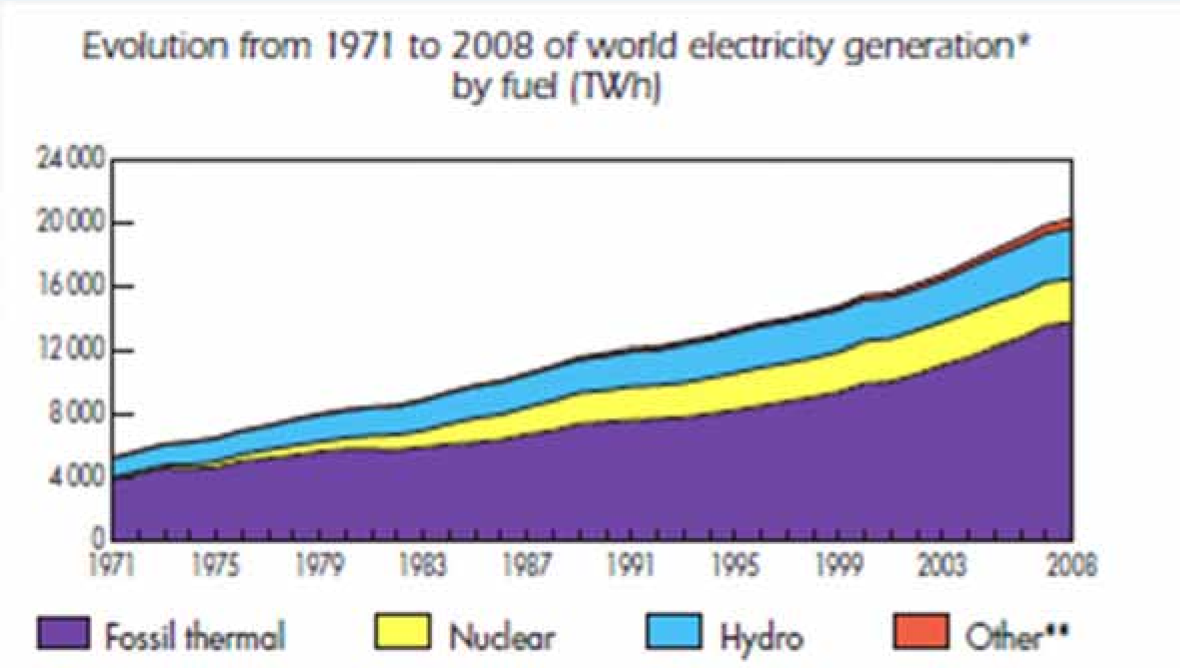


The worst polluters are:

- Electricity (0.45 kg/kWh)
  (mixed primary energy)
- Coal(0.35 kg/kWh)
  (industry and heating)
- Oil (0.27 kg/kWh)
  (industry and transport)
- Gas (0.22 kg/kWh)
  (industry and heating)

Electricity – A Worldwide Perspective

- Major contributor to Greenhouse Gas Emissions
- Rapidly increasing demand
  - Mainly met by new fossil thermal power stations!!!



Source: IEA

Electricity – A UK Perspective

- Major contributor to Greenhouse Gas Emissions
- Security of Energy Supply
- Future Generation Gap (old power stations)

Type	No. of Stations	No. of Stations Over 30 Years Old	%
Gas	19	14	73.7
Coal	16	13	81.3
Nuclear	12	6	50
Wind	66	0	0
Hydro	73	61	83.6
CCGT	35	0	0
Oil	3	1	33.3
CHP	5	0	0
Other	24	12	50
Total	253	107	42.3

Summary

- There is an ever increasing demand for energy worldwide.
- Electricity consumption accounts for a growing proportion of total energy demand
- Electricity is predominantly generated using hydrocarbon fuels using large (GW) power stations
- CO_2 emissions from electricity are a cause of global warming

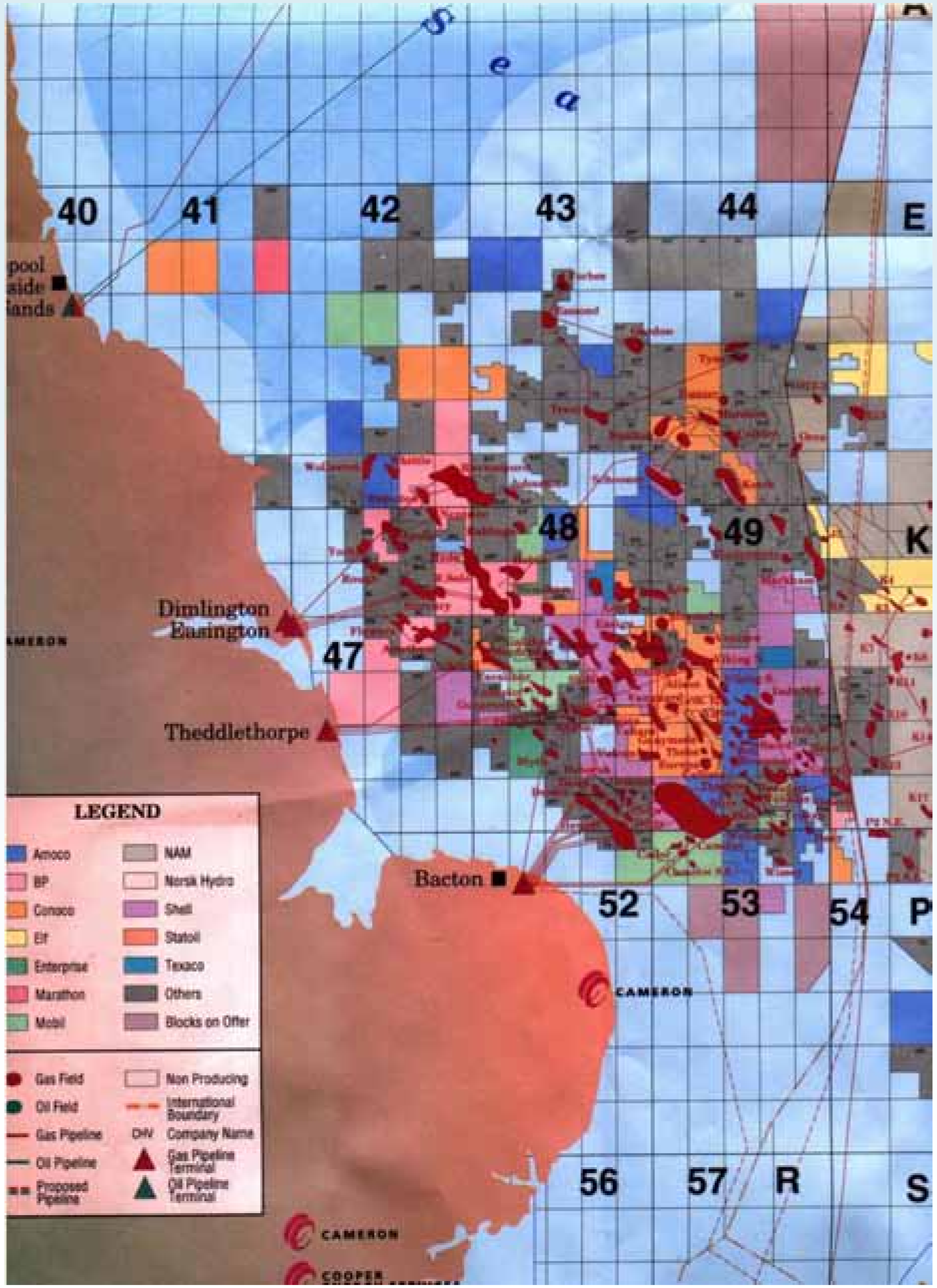
THE CEPV CONCEPT

Assumptions

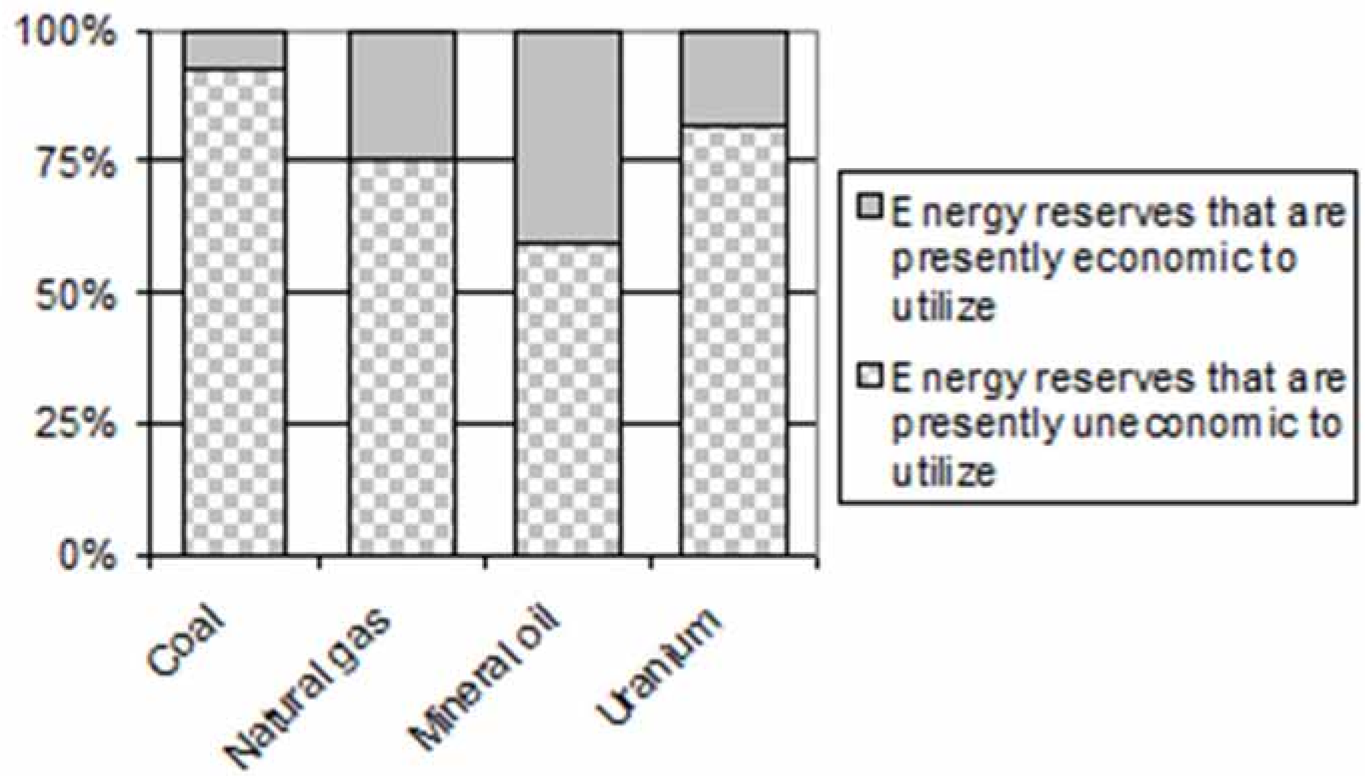
- Gas is the preferred fossil fuel as it produces less emissions than coal and oil. Renewables and nuclear are small and likely to remain so.
- UK has its own natural gas resources but is increasingly is dependent on imports.
- Majority of UK gas is offshore.
- These also apply to other nations.

UK Gas Fields

Southern North Sea gas field distribution showing how gas is not in a single large field but is found in many small pockets each requiring its own 'tap and pipe'.

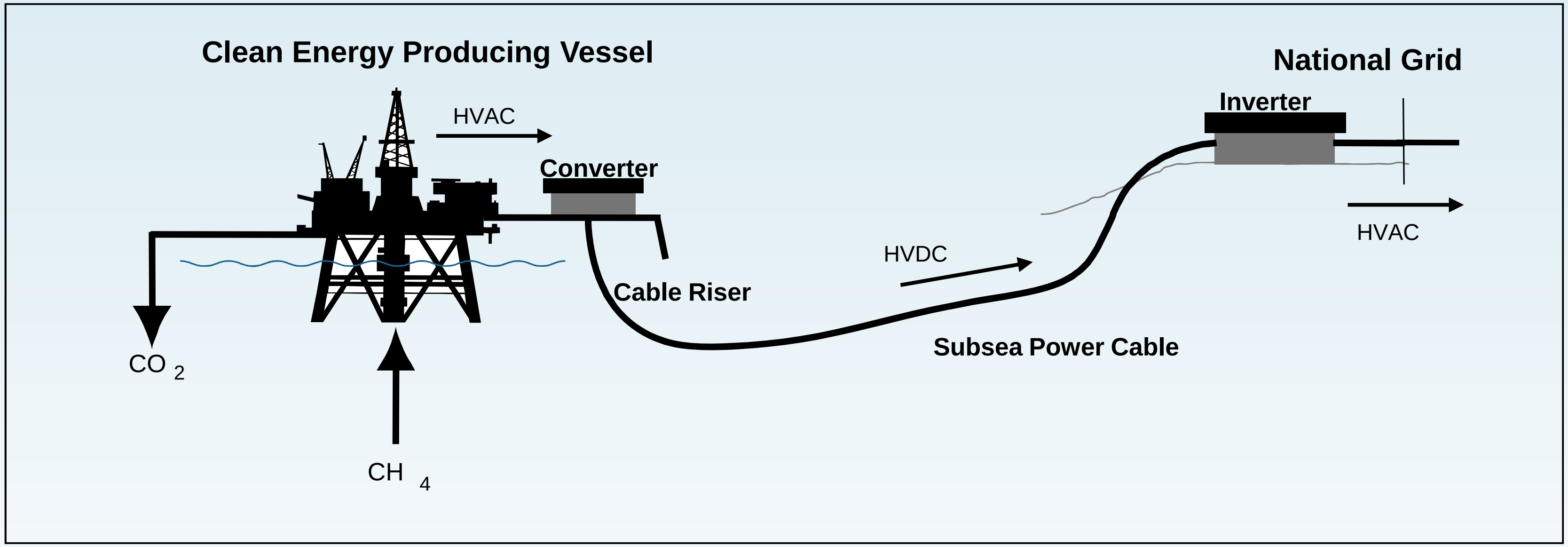


World Energy Resources



Significant amounts of natural gas is simply uneconomic to recover using pipeline!

The CEPV Concept



Onshore and Offshore Power Generation

Onshore

- Gas is supplied
- Gas supply is ‘clean’ gas
- Gas is at ‘market price’
- Conventional power plant
- Housed in a building
- Connection direct to NG
- Fixed location
- CCS requires long pipeline
- Known technical solution
- Known capital and running costs

Offshore

- Gas must be drilled
- Gas supply is ‘raw’ gas
- Gas is abandoned i.e. ‘free’
- ‘Marinised’ power plant
- Housed in a vessel or rig
- Connection is via subsea cable
- Location not fixed
- CCS requires shorter pipelines
- Unknown technical solution
- Unknown capital and running costs

Cost Comparison

Parameter	Shore-based Power Station	Offshore-based Power Station
Capital Cost	▪ Land purchase ▪ Power station ▪ Connection to gas supply ▪ Connection to National Grid ▪ Service requirements	▪ Licence to exploit natural gas ▪ Wellhead cost and riser ▪ Vessel ▪ Gas processing plant ▪ Power generating plant ▪ Subsea transmission cable ▪ Connection to National Grid
Running Cost	▪ Gas consumption ▪ Cooling water charges ▪ CO_2 emissions tax ▪ National Grid connection cost ▪ Maintenance cost ▪ Manning cost ▪ Taxes	▪ National Grid cost ▪ Maintenance cost ▪ Manning cost ▪ Taxes

Key parts of a 'Base Case' CEPV

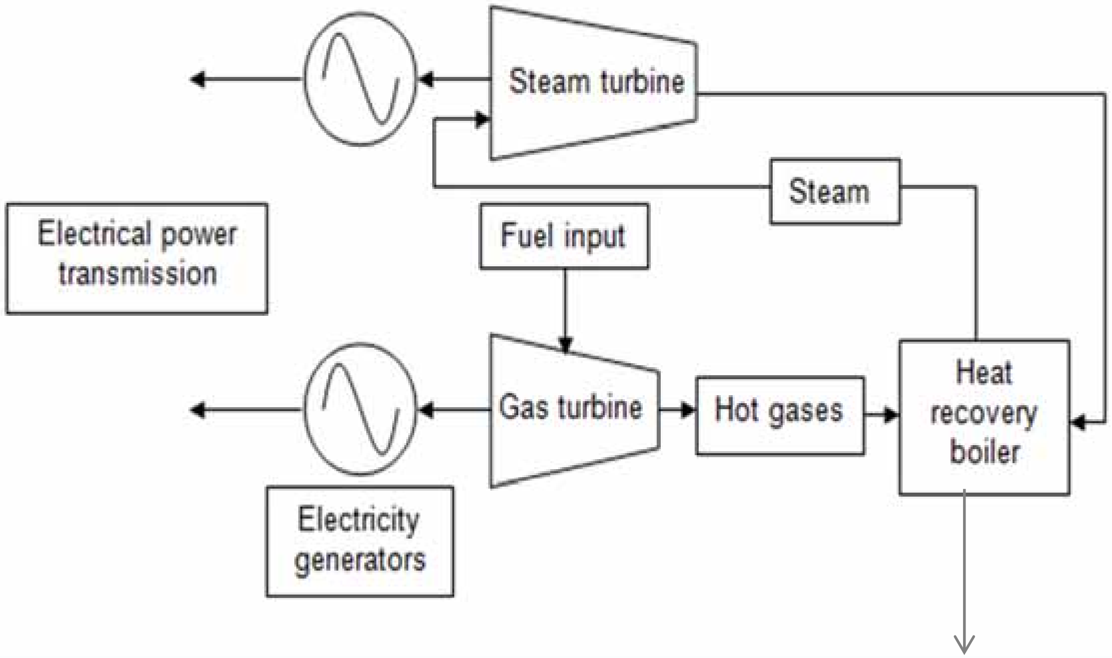
- Power Generation
  - Prime-movers
  - Electrical generation and distribution
  - Electrical power transmission
- Gas Side
  - Well head and riser system
  - Onboard gas processing plant
  - CO_2 Capture, compressing and storage (optional)
- Platform
  - Vessel
  - Ship services
  - Propulsion (optional)

Prime-movers

Prime-mover Selection Criteria

PRIME-MOVER TYPE	ADVANTAGES	DISADVANTAGES
DIESEL	Large range of powers Cheap £/kW Good efficiency ‘Marinised’ engines available	Limited versions use NG High maintenance
GAS TURBINES	Good power to weight ratio High powers available Some ‘marinised’ engines	Low efficiency Discrete size engines Expensive £/kW
STEAM TURBINES	Low maintenance High powers available Robust and ‘marinised’ plant	Heavy plant (requires boilers and condensers) Low efficiency
FUEL CELLS	Excellent efficiency Low maintenance Modular construction	Limited versions available Very expensive £/kW Almost no use offshore

Combined Cycle Gas Turbine Plant.



Exhaust

High efficiency through waste heat recovery.

Power Plant Selected for Base Case CEPV - Combined Cycle Gas Turbine (CCGT)

Specification
A 264 MW_e Rolls Royce Trent plant which consists of 4 x 51.9 MW_e gas turbine generator and 2 x 28.2 MW_e steam turbine generator operating using the waste heat generator.

Maximum Gas In-Flow Calculations
- **Intake air:** 12.32 million m^3 per day - **Gas consumption:** 1.24 million m^3 per day

Maximum Gas Out-Flow Calculations
Minimum Capacity for Base Case CEPV: - **Exhaust:** 33.7 million m^3 per day - **CO_2:** 1.31 million m^3 per day

CEPV – Natural Gas Flows

1. A natural gas flexible riser system ‘up-pipe’ allows ‘raw’ natural gas to be transferred from the wellhead to the CEPV.
2. Gas processing system ‘cleans’ the ‘raw’ natural gas prior to combustion by the CCGT power plant.
3. Condensates collected during gas processing are stored for later transfer to a shuttle tanker.

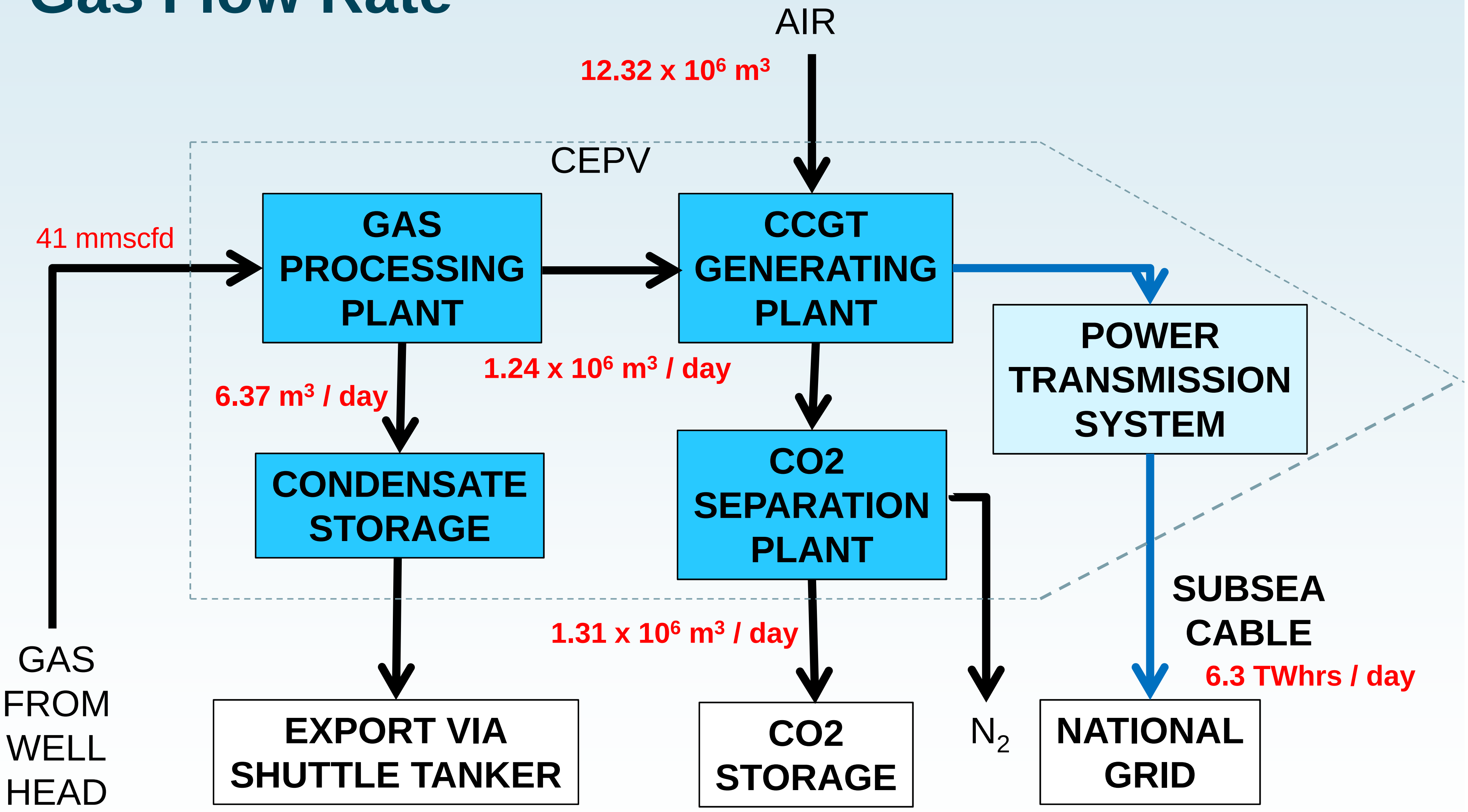
•

‘Raw Natural Gas’

Constituent	% Volume	Constituent	% Volume
Methane	93.00	Hexane	0.05
Ethane	3.00	Heptane	0.03
Propane	0.67	Octane	0.01
Isobutane	0.27	Nitrogen	2.12
Isopentane	0.08	CO_2	0.34
H_2S	0.43	Condensate	0.05

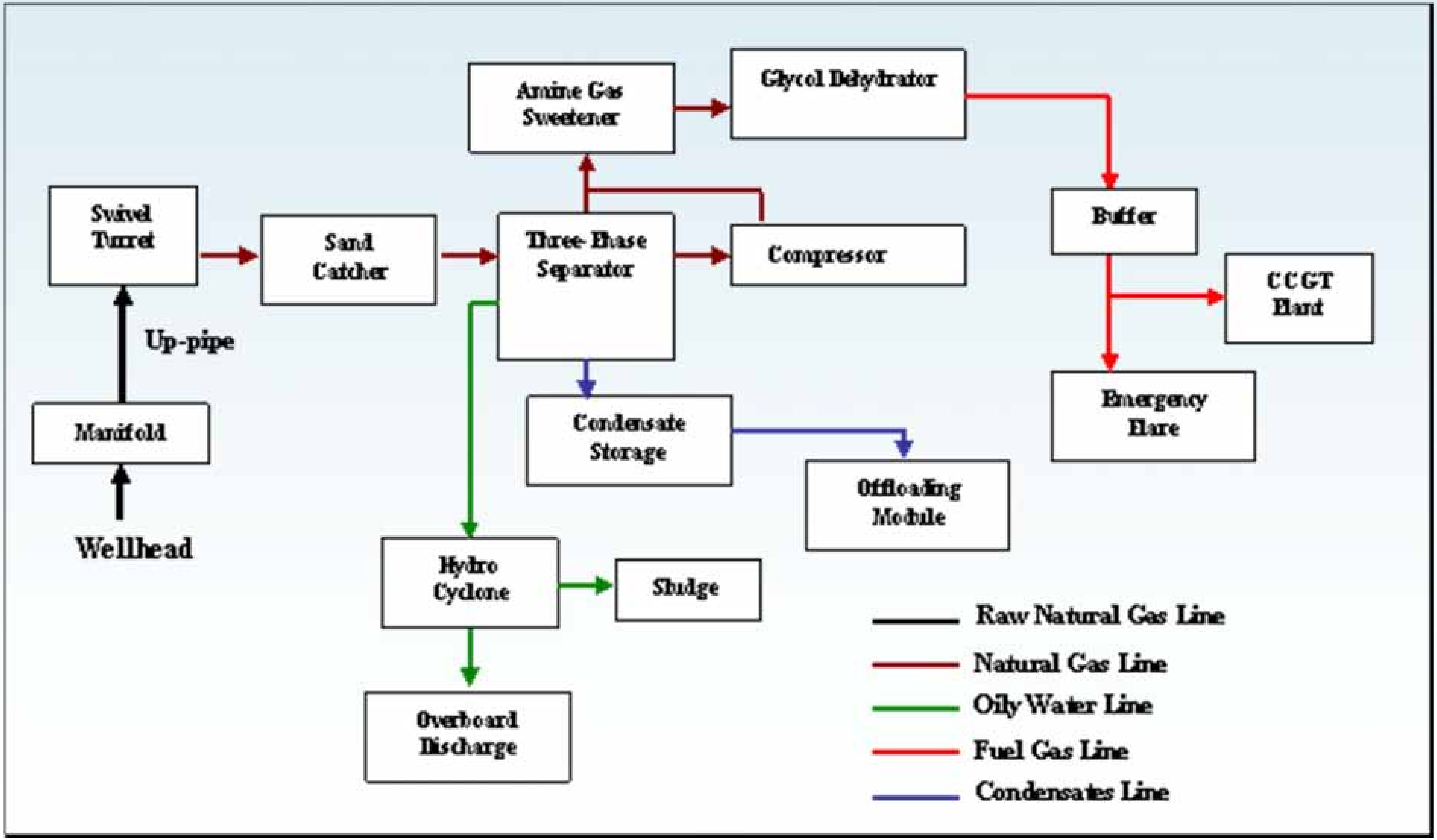
Typical Constituents in North Sea Natural Gas

Gas Flow Rate



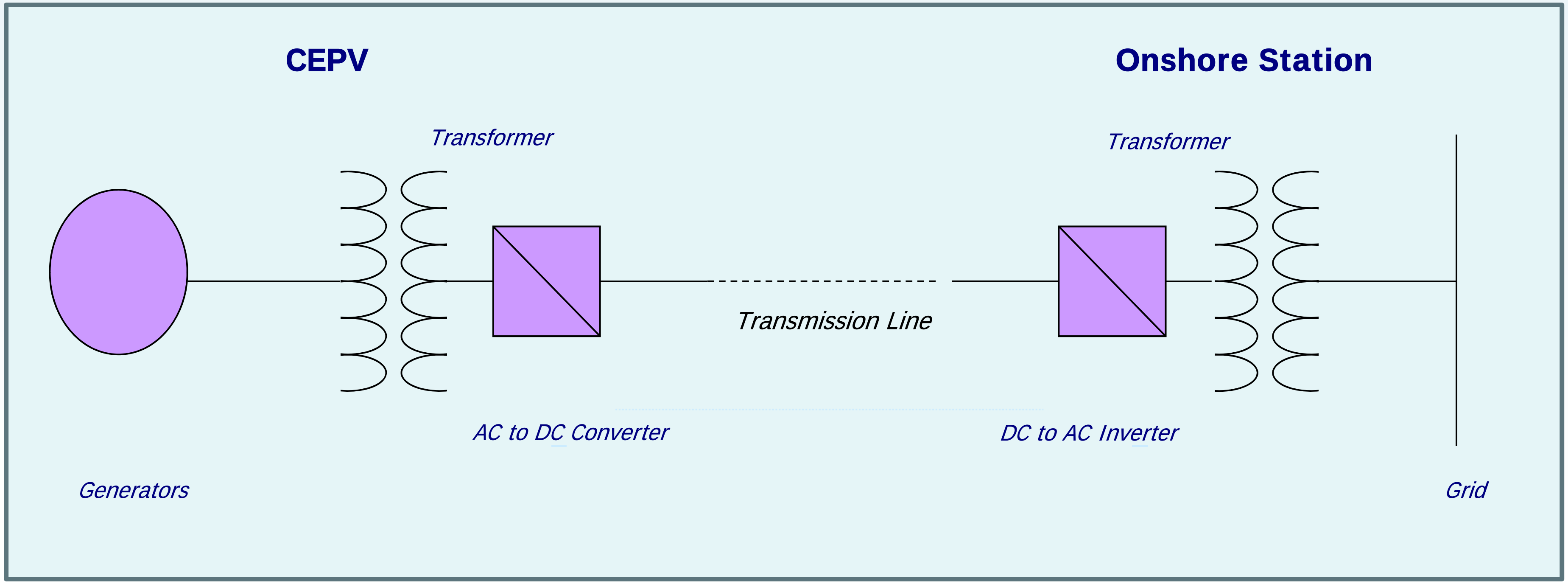
Process flow of gas to exhaust to exhaust and electrical power generation.

Gas Processing Plant - Wellhead to CCGT Plant

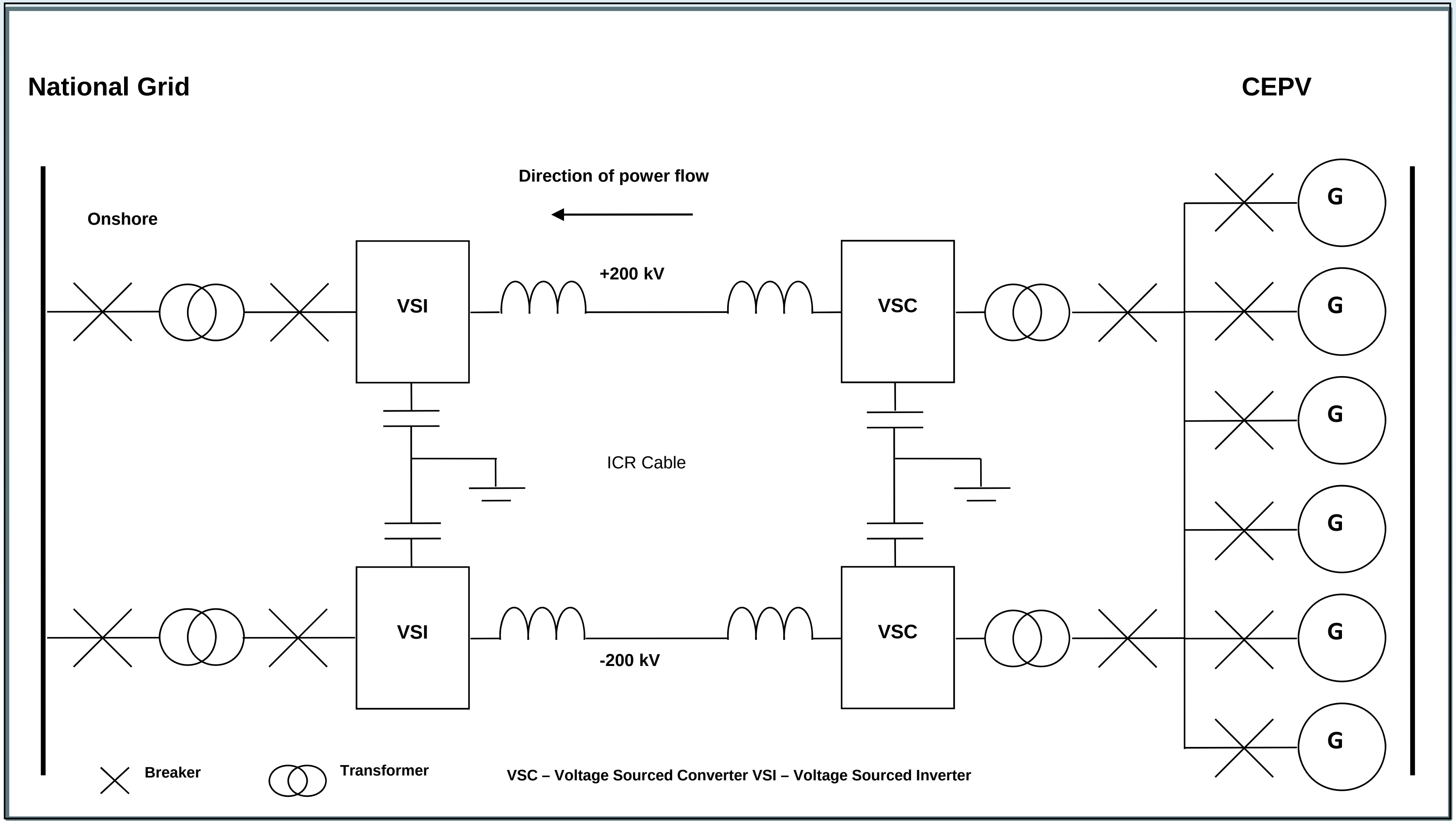


Transmission

• Electrical power conditioning prepares the generated electrical power for subsea transmission.
• A subsea electrical transmission system connects the CEPV to the shore-side electrical grid.

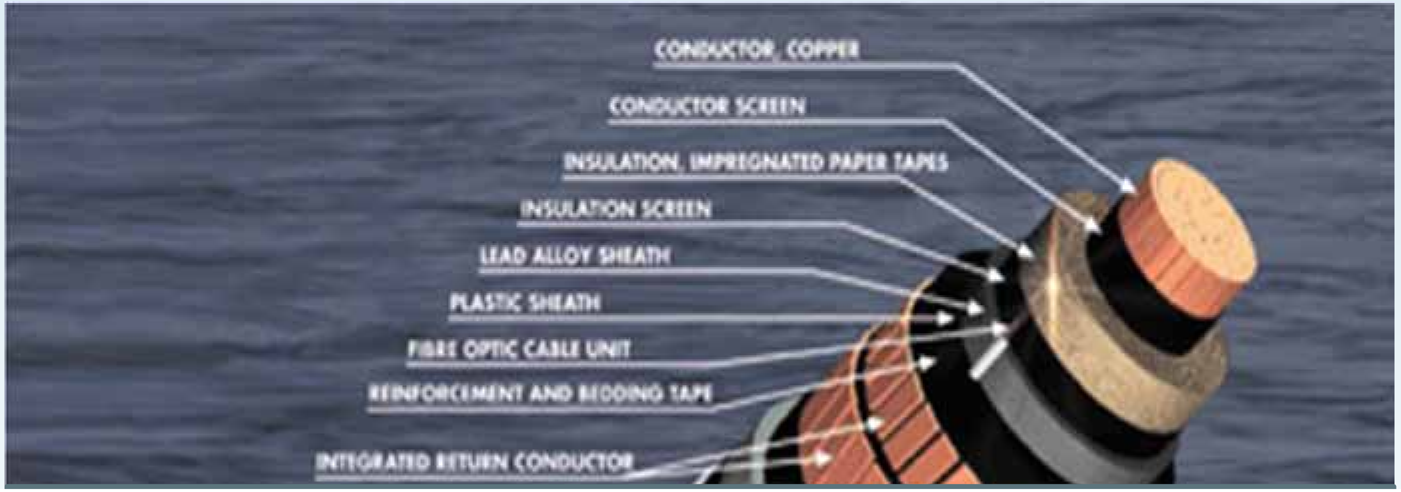


Proposed Bipolar HVDC System



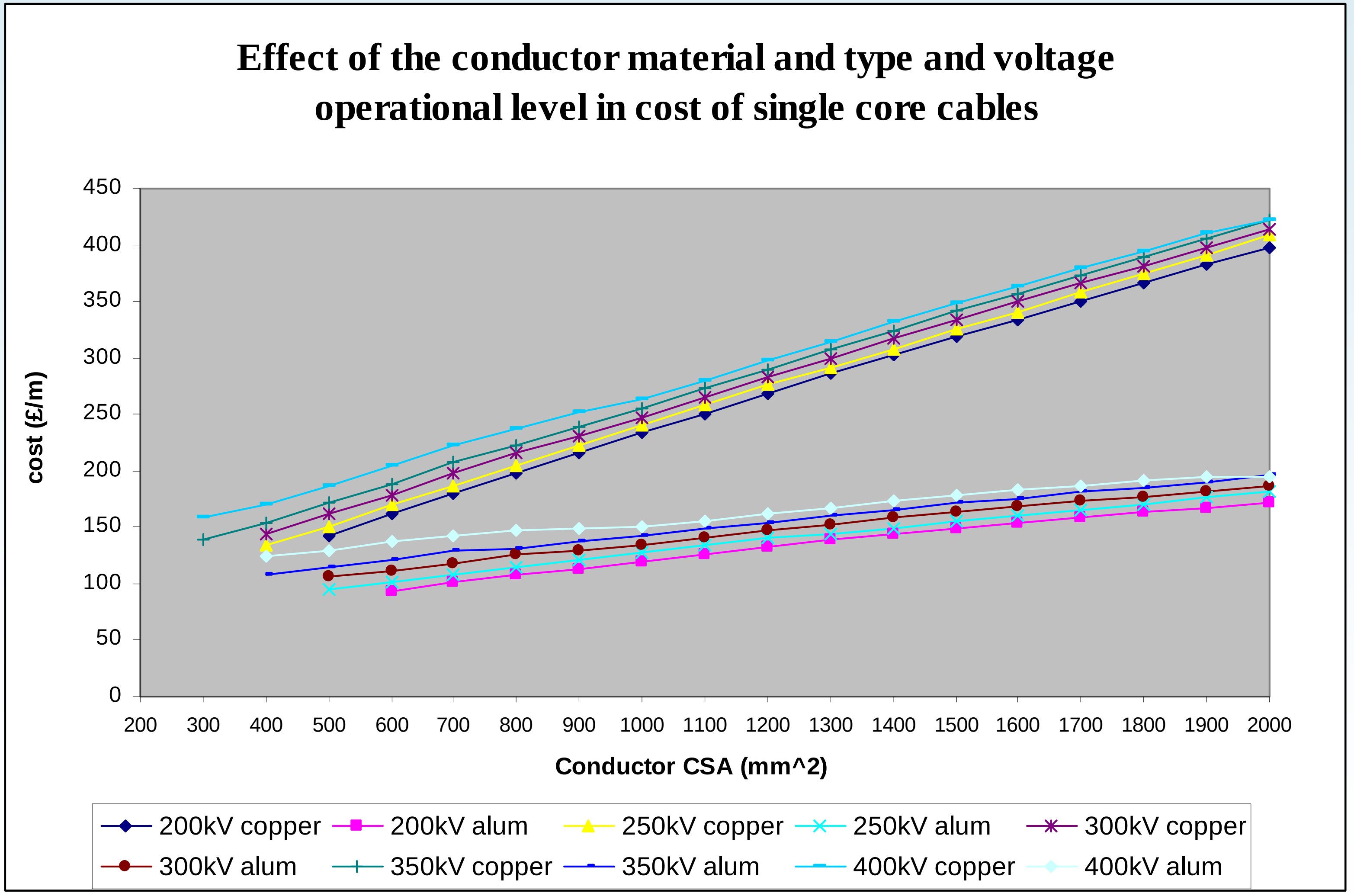
UCL

Typical HVDC ICR Subsea Cable



Operation mode	Cable type	Voltage (kV)	Conductor material	Conductor CSA (mm^2)	Cost (£/m)	Losses (MW/km)	Converter cost (£)	Additional losses (%)
HVDC	ICR	200	aluminium	1000	142	0.051	50 M	5*

Cable Costs



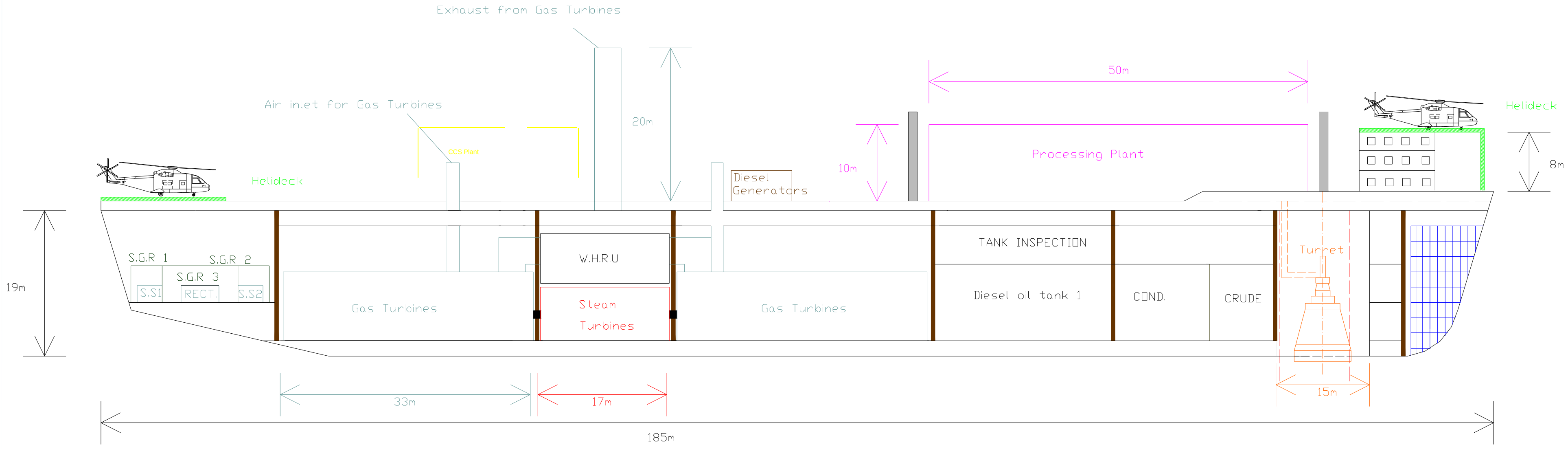
Effect of the conductor material and type and voltage operational level in cost of single core cables
450
400
350
300
250
200
150
100
50
0
cost (£/m)
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Conductor CSA (mm^2)
200kV copper
200kV alum
250kV copper
250kV alum
300kV copper
300kV alum
350kV copper
350kV alum
400kV copper
400kV alum

CEPV Electrical Power System

Equipment	Specifications	Manufacturer
Generators	6 x AC Synchronous Brushless Generators operating at 50 Hz and 25 kV: ▪ 4 x 61.1 MVA ▪ 2 x 33.2 MVA *Volume : 2,506 m^3*	GT Generators are supplied as part of Rolls Royce Trent package. ST Generators are supplied as part of Alstom steam turbines generator package.
Transformers	1 x Step-up Transformer on CEPV *Volume : 630 m^3*	Siemens Power Transmission and Distribution
Converters	VSC Converter/Inverter *Volume : 13,000 m^3*	ABB HVDC Light
Cable type	HVDC: 200 kV ICR Cable	ICR: Nexans Cables
Generator Circuit Breakers	Water-cooled, continuous current ratings up to 8,000 A *Volume : 80 m^3*	Hitachi GMCB SF6

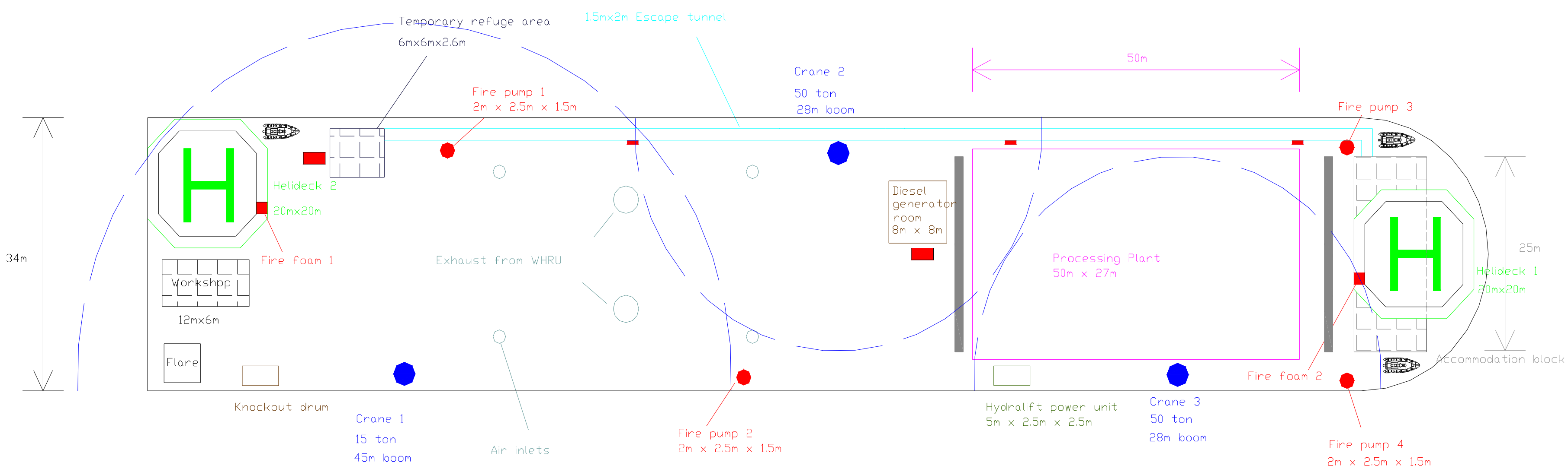
CLEAN ENERGY PRODUCING VESSEL			
DEEP DISPLACEMENT	67,037 TONNES	LIGHT SHIP DISPLACEMENT	62,026 TONNES
LENGTH (BP)	179 M	LENGTH (OA)	185 M
BEAM (WL)	34 M	DEPTH OF HULL	19 M
C_P	0.86	C_M	0.98
STORES	30 DAYS MAXIMUM	COMPLEMENT	20
OPERATIONAL AREA	NORTH SEA	HULL TYPE	MONO-HULL
PAYLOAD			
GAS PROCESSING PLANT		**CO_2 SEQUESTRATION PLANT**	
GAS TURBINE AND STEAM TURBINE GENERATORS		**SUBMERGED TURRET PRODUCTION SYSTEM**	
MACHINERY			
GAS PROCESSING PLANT	ELECTRICITY GENERATING PLANT	ELECTRICAL EQUIPMENT	**OTHER**
3-PHASE SEPARATOR Amine gas sweetener Glycol dehydration unit Gas compressor	4X ROLLS ROYCE TRENT GAS TURBINES AND GENERATOR 2x Alstom WHRU steam turbine and generator 4x Wartsila diesel generators	1X SIEMENS POWER TRANSFORMER 1x Siemens switchgear 1x Hitachi GMCB sf6 circuit breaker 1x ABB HVDC Light converter station	**1X APL SUBMERGED TURRET PRODUCTION UNIT** **1x condensate offloading facility**
TANKAGE			
CONDENSATE	1,000 M^3	SLUDGE AND WASTE OILS	**250 M^3**
FRESH WATER	400 M^3	NATURAL GAS BUFFER	**900 M^3**
DIESEL	1,000 M^3		

CEPV – Outline Design Study



Exhaust from Gas Turbines
Air inlet for Gas Turbines
20m
Diesel Generators
10m
50m
Processing Plant
Helideck
Helideck
8m
19m
S.G.R 1
S.G.R 2
S.G.R 3
S.S1
RECT.
S.S2
Gas Turbines
W.H.R.U
Steam Turbines
Gas Turbines
TANK INSPECTION
Diesel oil tank 1
COND.
CRUDE
Turret
33m
17m
15m
185m

PROFILE



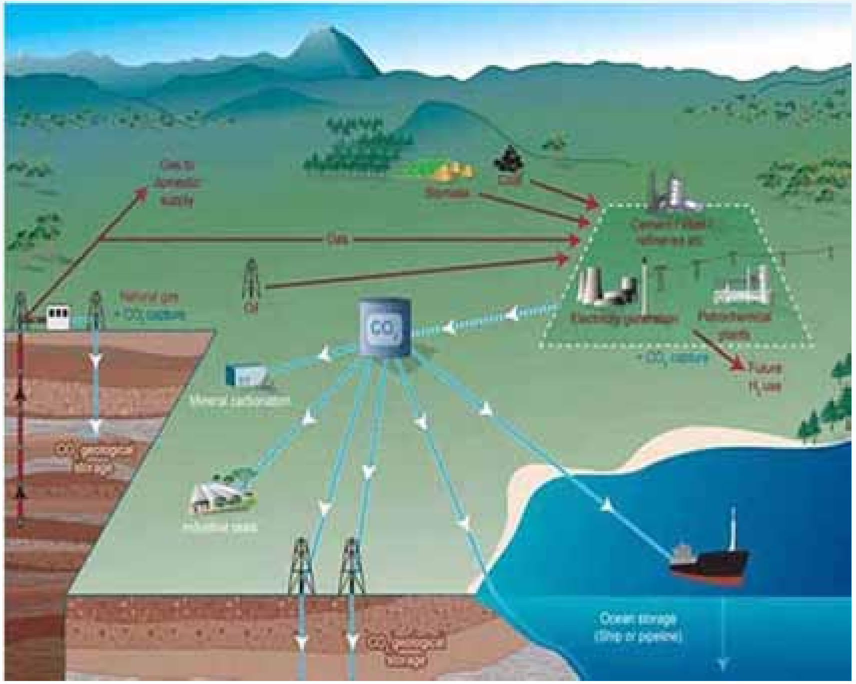
Temporary refuge area
6mx6mx2.6m
1.5mx2m Escape tunnel
Crane 2
50 ton
28m boom
50m
Fire pump 1
2m x 2.5m x 1.5m
Fire pump 3
34m
Helideck 2
20mx20m
Fire foam 1
Exhaust from WHRU
Diesel
generator
room
8m x 8m
Processing Plant
50m x 27m
25m
Helideck 1
20mx20m
Workshop
12mx6m
Flare
Accommodation block
Fire foam 2
Knockout drum
Crane 1
15 ton
45m boom
Air inlets
Fire pump 2
2m x 2.5m x 1.5m
Hydralift power unit
5m x 2.5m x 2.5m
Crane 3
50 ton
28m boom
Fire pump 4
2m x 2.5m x 1.5m

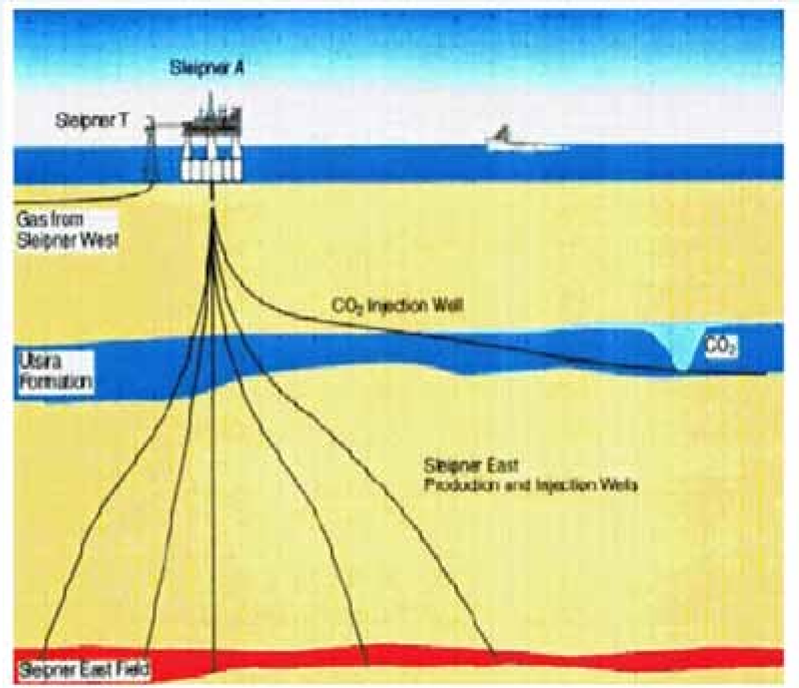
Specification of the Base Case CEPV

Equipment	Specifications/Requirements	Comments
CCGT electricity generating plant	CCGT Plant for Base CEPV: A 264 MW_e Rolls Royce Trent plant which consists of 4 x 51.9 MW_e gas turbine generator and 2 x 28.2 MW_e steam turbine generator. Volume: 11,713 m^3	- Intake air: 12.32 million m^3 per day. - Fuel consumption: 1.24 million m^3 per day. - Exhaust Generated: 33.7 million m^3 per day.
Gas Processing Plant	Gas processing plant to consist of a three phase separator, condensate offloading facility, amine sweetener, glycol dehydration plant, natural gas buffer and emergency flare. Volume: 13,500 m^3	- Minimum gas flow for Base Case CEPV: 41 mmscfd. - Natural gas required: 1.24 million m^3 per day. - Condensate production: 6.37 m^3 per day. 1x MAN Turbo Compressor
CO_2 Capture and Sequestration	Post-combustion capture with geological sequestration into depleted oil and gas field.	Minimum Capacity for Base Case CEPV: 33.7 million m^3 exhaust gas per day. 1.313 million m^3 CO_2 per day.
Turret	Turret to accommodate: natural gas up-pipe, CO_2 down-pipe and cable riser	Natural gas: 41 mmscfd CO_2 1.313 million m^3 per day 250 MWe generated electricity

CO_2 Capture and Sequestration

- CCS is a technology under development.
- Different solutions for capture are being researched
- Different solutions for storage are being researched





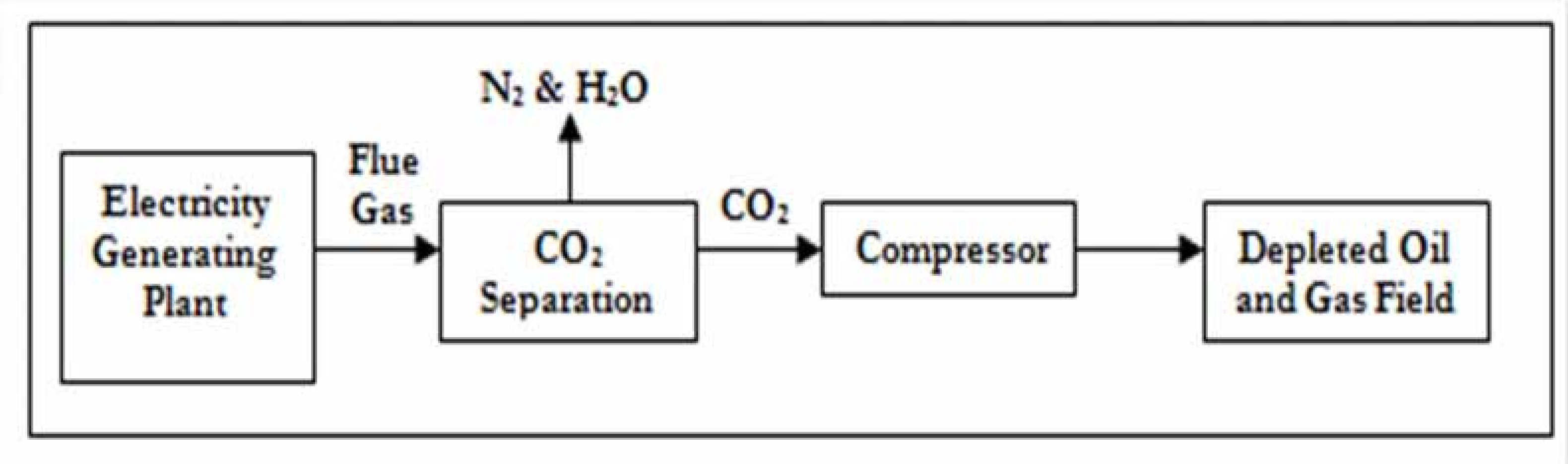
Carbon Capture and Storage Schemes

Project name	Country	Injection start (year)	Approximate average daily injection rate (tCO_2 day-1)	Total (planned) storage (tCO_2)	Storage reservoir type
Weyburn	Canada	2000	3,000-5,000	20,000,000	EOR
In Salah	Algeria	2004	3,000-4,000	17,000,000	Gas field
Sleipner	Norway	1996	3,000	20,000,000	Saline formation
K12B	Netherlands	2004	100 (1,000 planned for 2006+)	8,000,000	Enhanced gas recovery
Frio	U.S.A	2004	177	1600	Saline formation
Fenn Big Valley	Canada	1998	50	200	ECBM
Qinshui Basin	China	2003	30	150	ECBM
Yubari	Japan	2004	10	200	ECBM
Recopol	Poland	2003	1	10	ECBM
Gorgon (planned)	Australia	~2009	10,000	unknown	Saline formation
Snøhvit (planned)	Norway	2006	2,000	unknown	Saline formation

Examples of some current Carbon Capture and Storage Technologies.

CO_2 Separation

- Separate CO2 from exhaust (Capture process)
- Capture processes
  - Calcium cycle capture
  - Cryogenic capture
  - Amine capture
- CEPV selected ABB-Lummus System
  - 6,290 m^3 of CO_2 per hour on a single stream



Transportation of CO_2

- The transportation of CO_2 by ships is already being done but only on a small scale. Larger ships would be required for the sequestration of CO_2
- The CO2 is generally transported as a pressurised cryogenic liquid e.g. at 6 bar and at a temperature of -55 deg. C - energy intensive process.
- The CEPV avoids the need to transport CO_2. CO_2 would simply be transported in short pipelines to a CO_2 wellhead.

CO_2 Sequestration

- Existing technology already in use for CO_2 enhanced oil recovery. CO_2 is easily handled and is large inert, it can be transported at high pressures through pipelines.
- There is extensive pipelines carrying $C0_2$ in existence some of which are offshore.
- There are internationally recognised standards for the design, construction and monitoring of pipelines carrying CO_2 offshore and onshore.

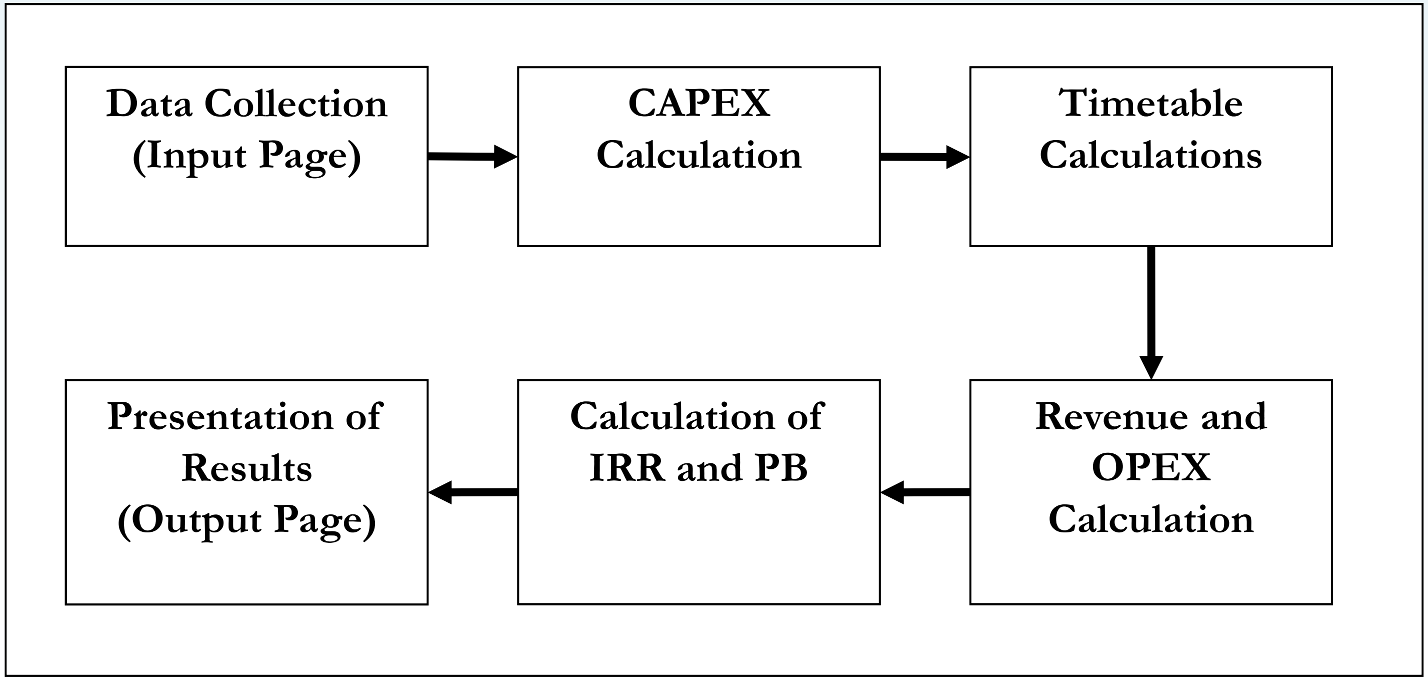
CEPV Economic Model

Input Page:

- Financial information
- Plant Technical Data
- Field Information Data
- Transmission Data

Output Page:

- CAPEX, OPEX
- IRR, PP, NPV



Input Page

Microsoft Excel - Base

File Edit View Insert Format Tools Data Window Help

CASE NAME	BASE CASE		
	BASE CASE		
FINANCIAL DATA			
		Base	
Inflation Rate %		2	2
Interest Rate %		5	5
Gearing (MAX 100%)		25	25
Corporation Tax %		30	30
Carbon Tax $/tonne CO2		0	0
Length of project (yrs, MAX 25)		25	25
Electricity Av. Revenue £/MWh		38	38
Condensate Sale Price ($/bbl)		90	90
Exchange Rate	£1=	$1.50	$1.50
Discount Rate (for NPV output)		5	5
PLANT DATA			
VESSEL + GEN SET			
SYSTEM OPTION (see Gen Set Options)		5	5
DP installed	1/0	1	1
DP used	1/0	1	1
Maintenance:-	days planned/yr	6	6
	days unplanned/yr	6	6
Gas Processing (% gen. Power)		5	5
CO2 Sequestration	1/0	0	0
Ship time to refit (yrs)		15	15
TRANSMISSION DATA			
TRANSMISSION TYPE	AC/DC	DC	DC
Grid Connection	1/0	1	1
AC OPTIONS			
Cable Formation flat/trefoil		trefoil	trefoil

FIELD DATA	1st	2nd	3rd	4th	5th
Distance to shore (km)	150	150	150	60	60
Base	150	150	150	60	60
Field size (bn m^3)	8	0	0	0	0
	8	0	0	0	0
Wells (production)	2	0	0	0	0
	2	2	1	1	1
Relocation time (yrs)	0.5	0.5	0	0	-
	0.5	0.5	0.5	0.5	-
Gas price (£/MMSCF)	0	0	0	0	0
	0	0	0	0	0
Gas quality MJ/m^3	38	38	38	38	38
	38	38	38	38	38
Condensate ratio bbl/mmscf	40	40	40	40	40
	40	40	40	40	40
Wells (exploration, abandoned)	1	1	0	0	0
	1	1	0	0	0
Water depth (m)	90	90	0	0	0
	90	90	40	40	40

DC OPTIONS			
Single core sea return	1		
Metallic return	2	3	3
ICR	3		
Voltage 200 250 300 350 400 kV		200	200
Conductor Material cu/al		al	al
Insulation Material paper/XLPE		paper	paper

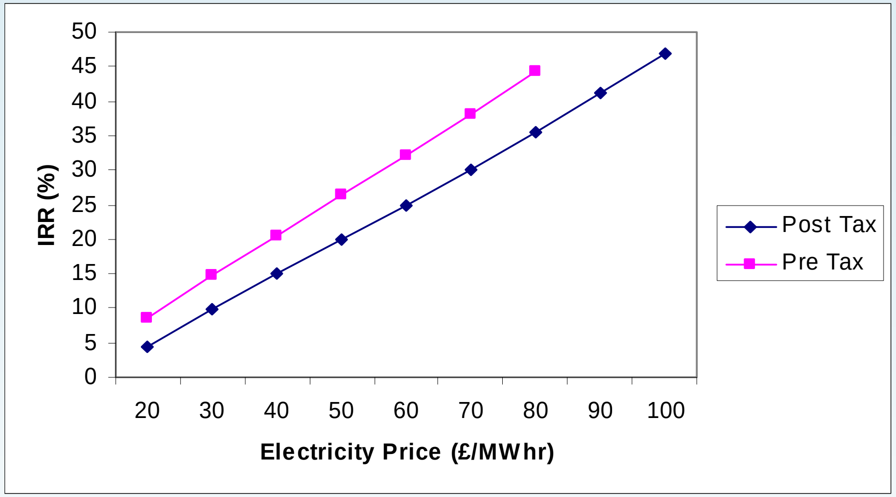
USER INPUT / NGT / Gen Set Options / Summary / Analysis / Costs /

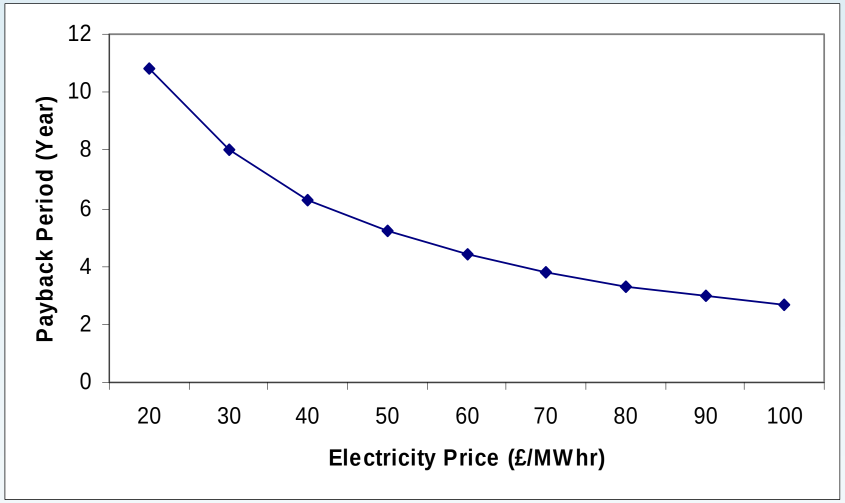
Ready Calculate NUM

Output Page

			Gas-to-Wire	
CAPEX				
	Vessel			
	Basic Vessel		66.3	(all £M)
	Generator Set		153.7	
	Sequestration Plant		0.0	
	Electrical Equipment		44.2	
	Platform			
	Structure		-	
	Processing Plant		-	
	Wells and Subsea Installation		56.1	
	Risers (Dynamic)		2.8	
	Transmission Cables		57.5	
	Pipeline		-	
	Onshore Electrical Equipment		44.2	
	Connections		0.1	
	Miscellaneous		0.0	
	Relocations		0.0	
	Decommissioning		12.7	
		Total	437.4	£M
OPEX		First year	17.3	£M
		Total	258.4	£M
REVENUE	Revenue per year (max.)		98.5	£M
		Gross Revenue	1477.2	£M
IRR		Post Tax	13.97	%
		Pre Tax	19.42	%
NPV		NPV at 5%	241.1	£M
PAYBACK		Payback Period	6.6	years

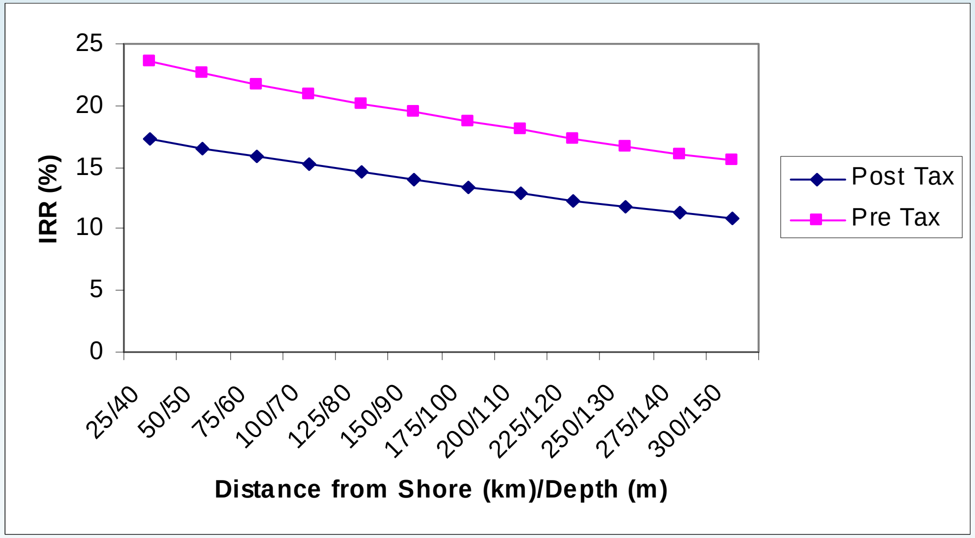
Results: Impact of Electricity Sales Price

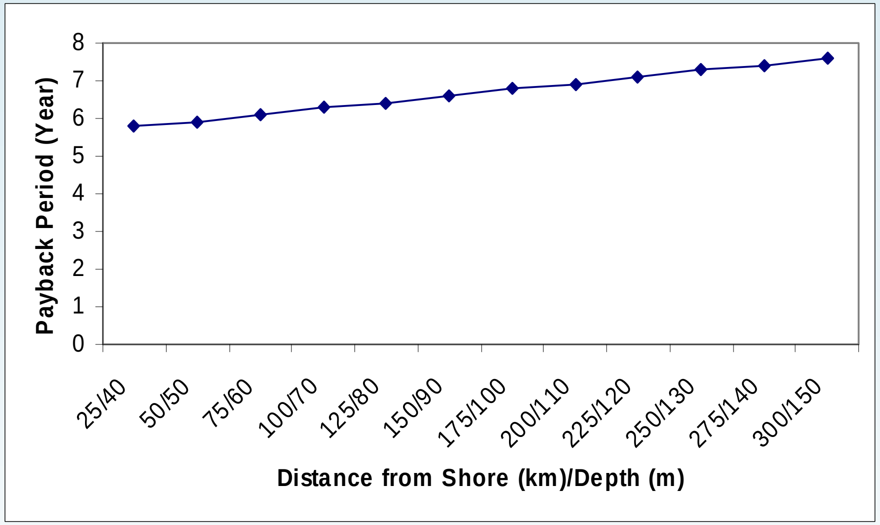




- CEPV demonstrates satisfactory payback and IRR provided electricity price is about £60/MWhr
- An upward trend of electricity price is desirable to ensure profitability

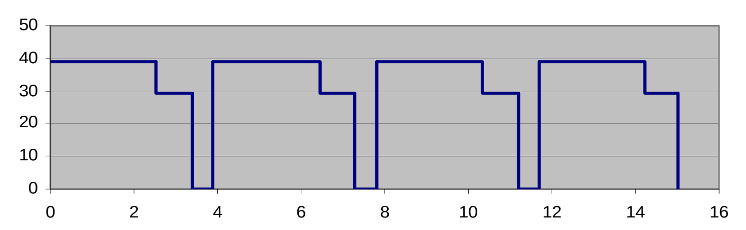
Impact of Distance of Shore and Water Depth

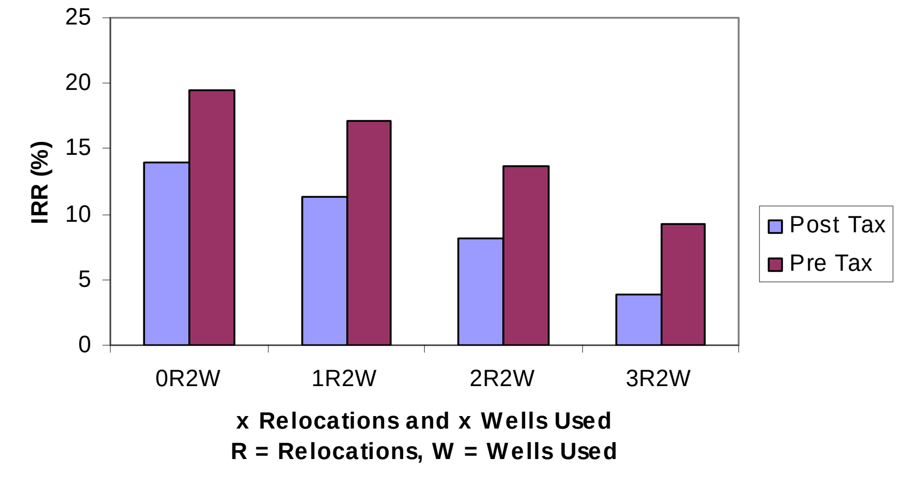


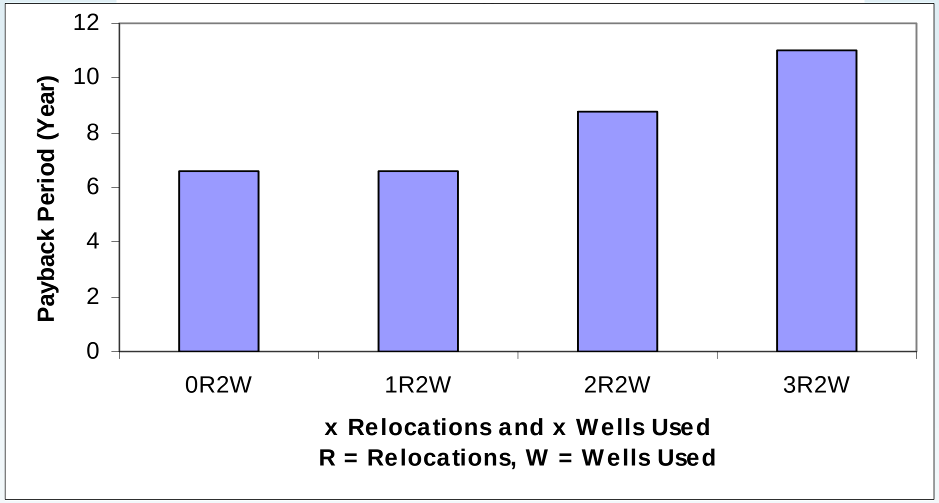


- Generally, further offshore means greater depth and increased costs for cable and up and down pipes.
- However the impact on IRR and payback is modest.

Impact of Relocations







- Increasing the number of wells allows increased gas flow as the gas field depletes but is more expensive.
- Increasing the number relocations (which will include down time) means reduced IRR and increased payback.

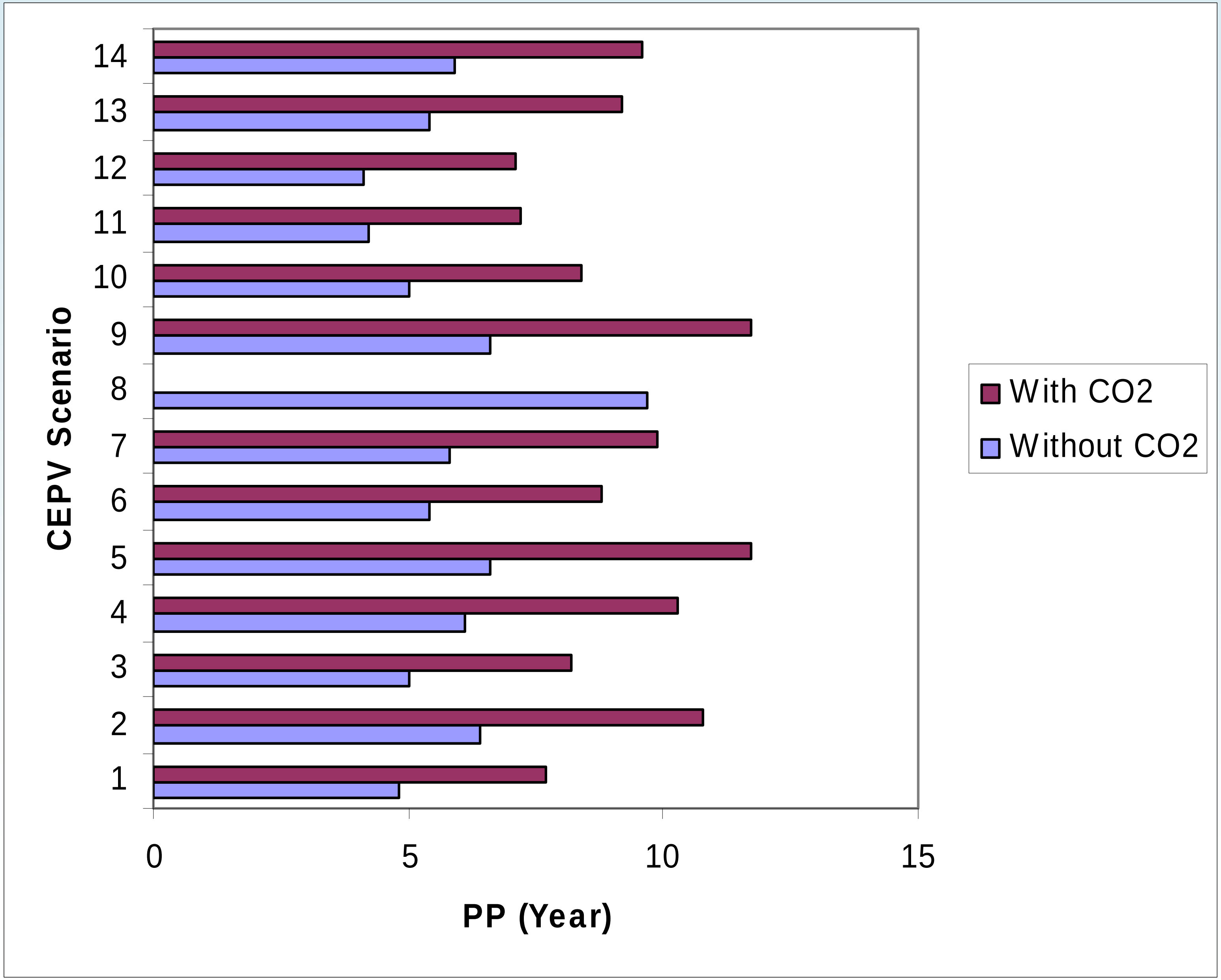
Economics of CO_2 Sequestration

Parameter	Without CO_2 Sequestration	With CO_2 Sequestration
IRR (%)	19.42 (13.97)	6.27 (3.28)
PP (Years)	6.6	11.7
NPV (£M)	241.1	-57.3
CAPEX (£M)	437.4	595.3
First Year OPEX (£M)	258.4	327.7

- The impact of using CO_2 Sequestration was found to be detrimental to the economic viability of the Base Case CEPV without CO_2 CCS.
- Further studies looked at the level of subsidy required and/or Carbon Tax to make the CEPV with CO_2 Sequestration economic.

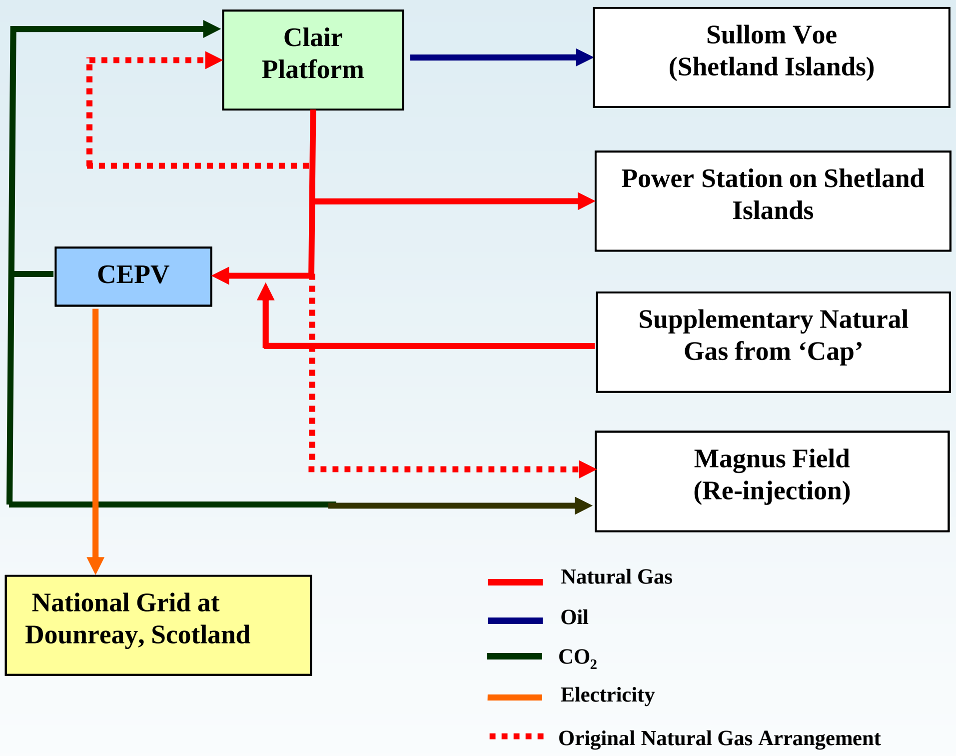
Power Plant and Generator Set Options

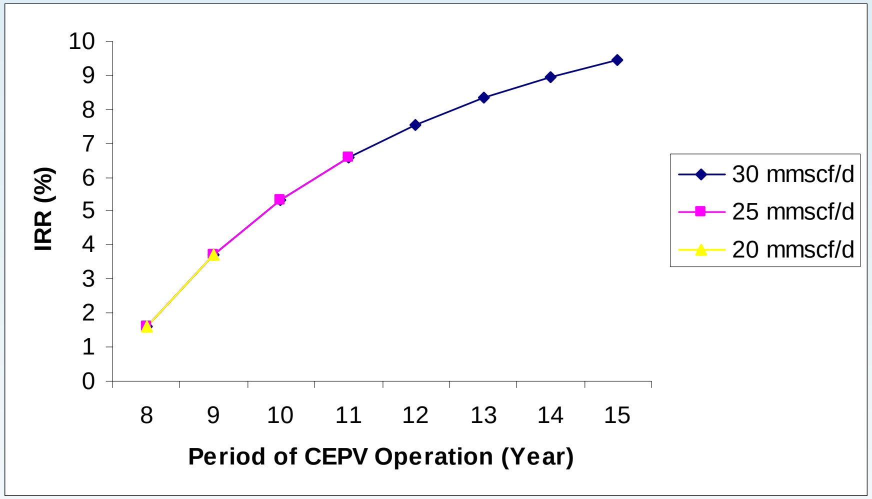
Gen Set	Output (MWe)	η (%)	Total NG req. per day (tonne)	Minimum gas flow to achieve maximum production (mmscf/d)	Total NG prod. per day (tonne)	Volume of NG prod. per day (million m^3)	O_2 req. per day (tonne)	Volume of intake air req. per day (million m^3)	CO_2 prod. per day (tonne)	Volume of CO_2 prod. per day (million m^3)
1	258	37	1244	64	1256	1.76	4990	17.52	3481	1.87
2	250.8	51	877	45	883	1.24	3508	12.32	2447	1.31
3	502	52	1722	88	1726	2.42	6861	24.09	4786	2.57
4	279	52	957	49	961	1.35	3820	13.42	2665	1.43
5	264	54	872	45	883	1.24	3508	12.32	2447	1.313
6	267	51	934	48	942	1.32	3742	13.14	2611	1.4
7	263.2	54	869	45	883	1.24	3508	12.32	2447	1.313
8	157	54	519	27	530	0.74	2105	7.39	1468	0.79
9	264	54	872	45	883	1.24	3508	12.32	2447	1.313
10	328	49	1194	61	1197	1.68	4756	16.7	3318	1.779
11	400	54	1321	68	1334	1.87	5302	18.62	3698	1.98
12	502	52	1722	88	1726	2.42	6861	24.09	4786	2.57
13	259.5	42	1102	57	1118	1.57	4444	15.61	3100	1.66
14	258	55	837	43	844	1.18	3352	11.77	2339	1.25

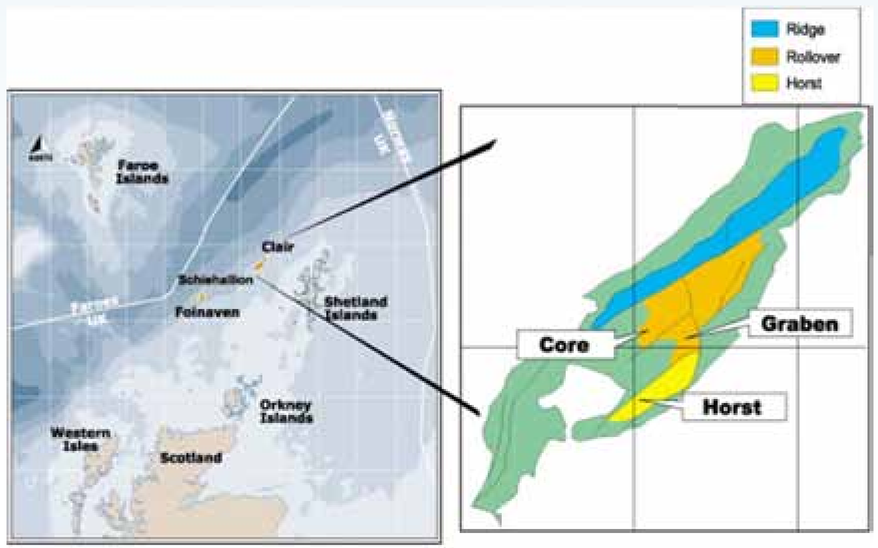


CEPV Scenario
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
5
10
15
PP (Year)
With CO2
Without CO2

Case Study – Clair Field

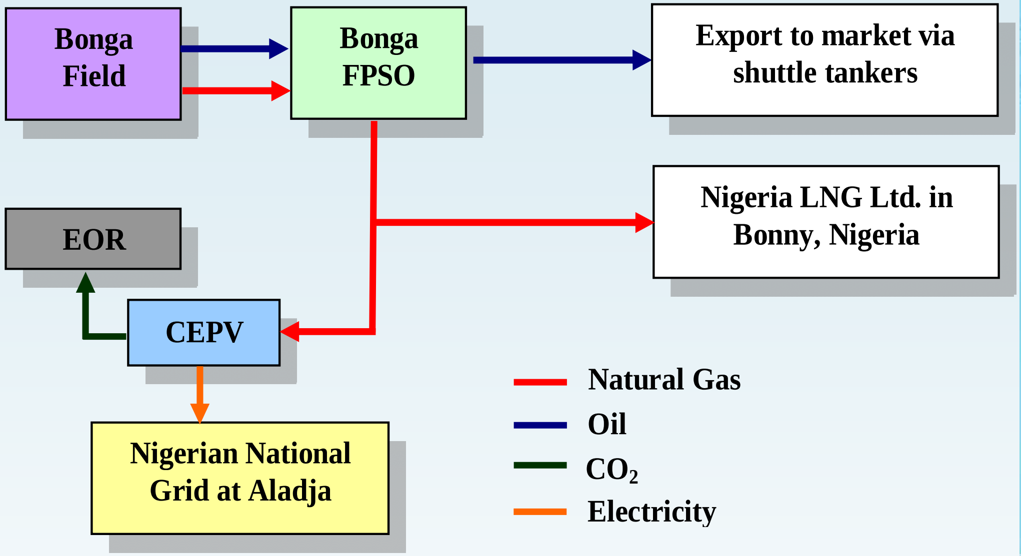






Clair Field is West of Shetland and is mainly an oil field with natural gas.

Case Study – Bonga Field



Options	CAPEX (£M)	OPEX (£M)	NPV (£M)	IRR (%)	PP (Years)	Power Gen. (MW)	Power Exp. (MW)	Viability	Ranking
1	521	118.1	31.4	6.46	7.4	258	245.1	Y	3
2	601.3	132.8	-124.2	0.05	-	250.8	238.3		
3	934.2	210	30.7	5.79	7.6	502	476.9	Y	4
4	643	144.9	-112.5	0.57	9.7	279	265.1		
5	601.8	218.7	-158.3	-	-	264	250.8		
6	537.8	117.9	-31.7	3.51	8.4	267	253.7		
7	535.1	109.4	-79.2	1.25	9.3	263.2	250.0		
8	560.9	193	-288.6	-	-	157	149.2		
9	601.8	218.7	-158.3	-	-	264	250.8		
10	654.1	151	-5.5	4.77	7.9	328	311.6		
11	695.1	166.4	91.6	8.16	8.66	400	380.0	Y	2
12	833.3	203	127.1	8.64	6.8	502	476.9	Y	1
13	542.7	188.3	-48.4	2.74	8.7	259.5	246.5		
14	557.3	125.3	-71.5	1.76	9.1	258	245.1		

Conclusions

- If the world is serious about reducing global warming through a reduction in emissions then it must either reduce its dependence on fossil fuels or learn to avoid emitting CO_2 into the atmosphere.
- Energy sources are becoming more remote – much lies offshore in remote locations known as stranded gas reserves.
- The CEPV is an offshore power concept that appears technically and economically feasible for exploiting some stranded gas reserves
- The CEPV with CO_2 Sequestration requires subsidy to make it economic although technically feasible to achieve.