CO_2 Capture Project

Economics and Case Studies

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(modified from presentation of T. Mikus to NETL)

Outline

- Project objectives
- Economic methods
- Case studies
- Economic results

Project Objectives

- Achieve major reductions in the cost of CO_2 Capture and Storage:
  - 50% reduction when applied to a retrofit application.
  - 75% reduction when applied to a new build application.

Approach

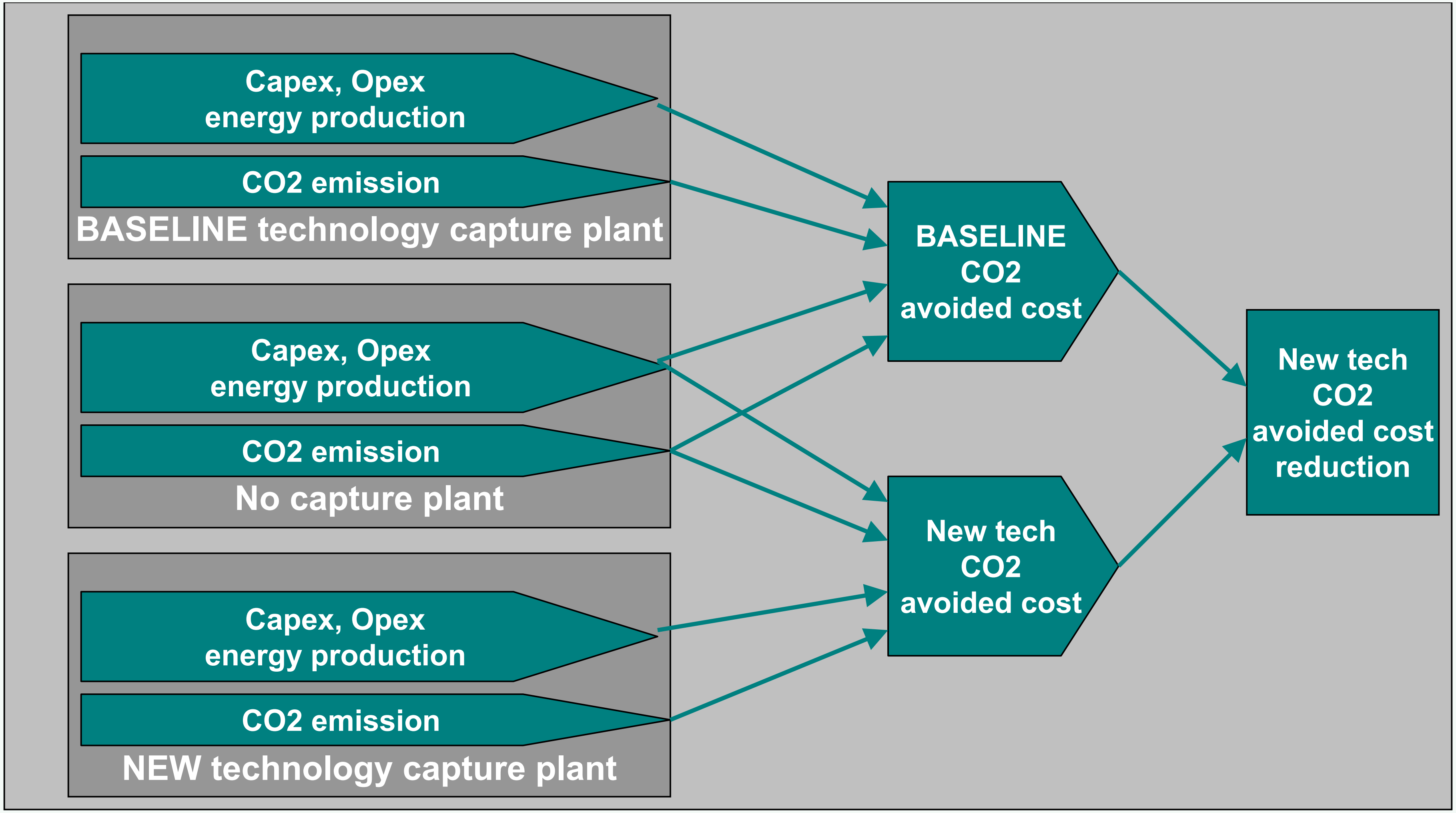
- **Capture Technologies**
  cost-reducing development of pre/oxy/post- technology options

- **Case Studies = “Scenarios”**
  or representative, real-life industrial application plants

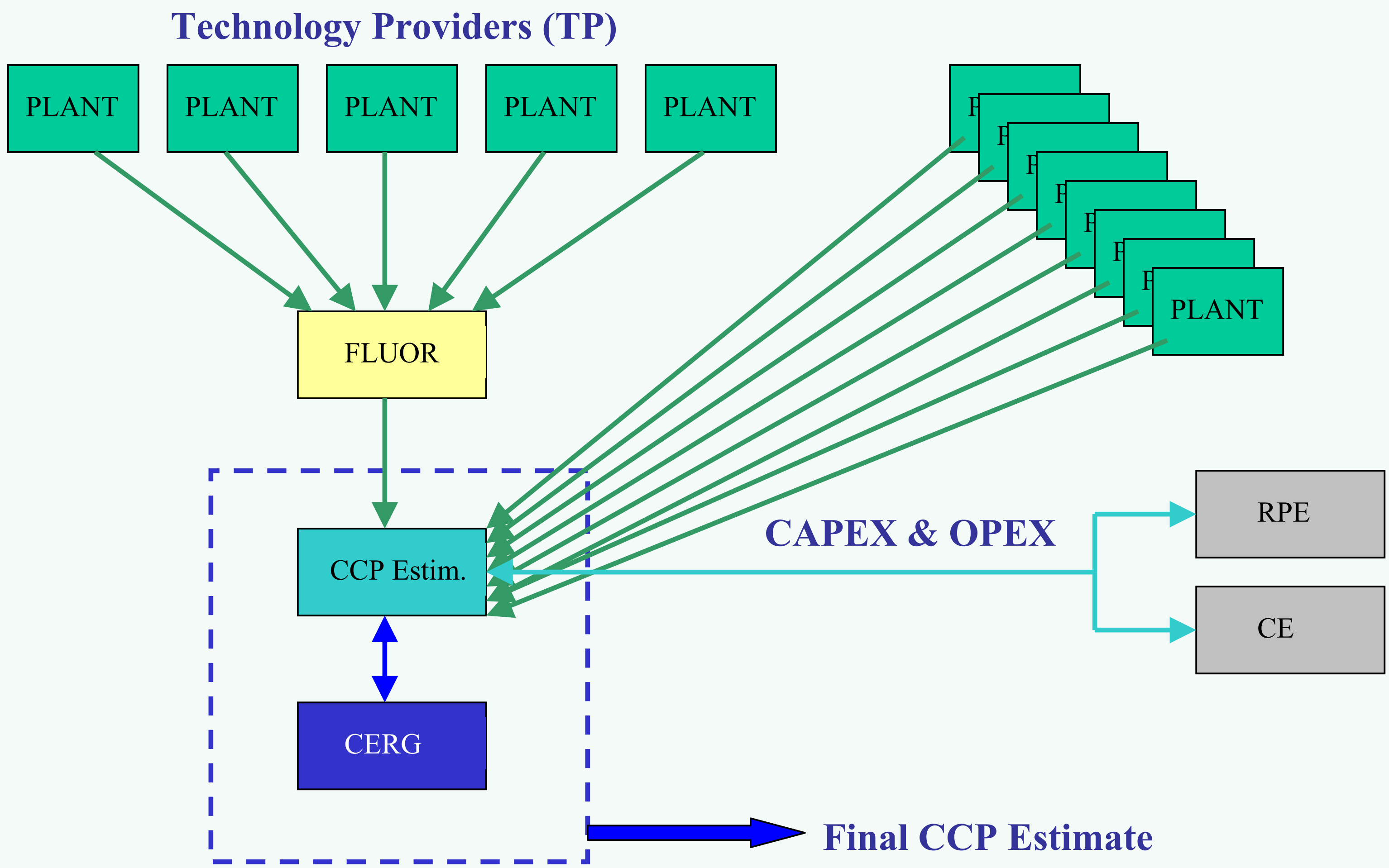
- **Baselines**
  or currently best available capture technologies (mainly post-comb/ amine-solutions) established as benchmarks in evaluating

- **New Technologies**
  capture performance and costs

Economic Criterion - CO2 Avoided Cost



CCP Cost Estimation Process – the Players

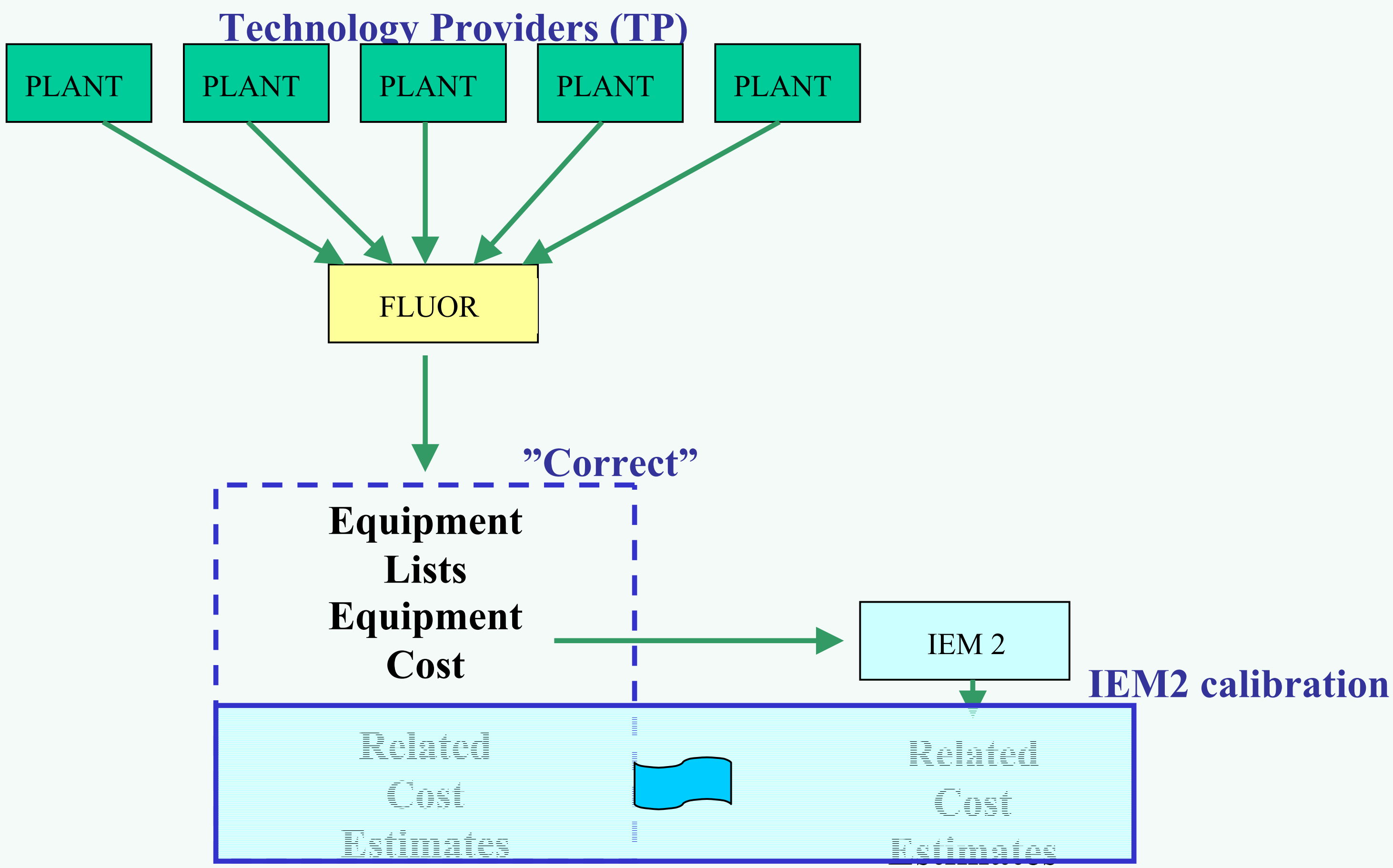


Cost Estimation:

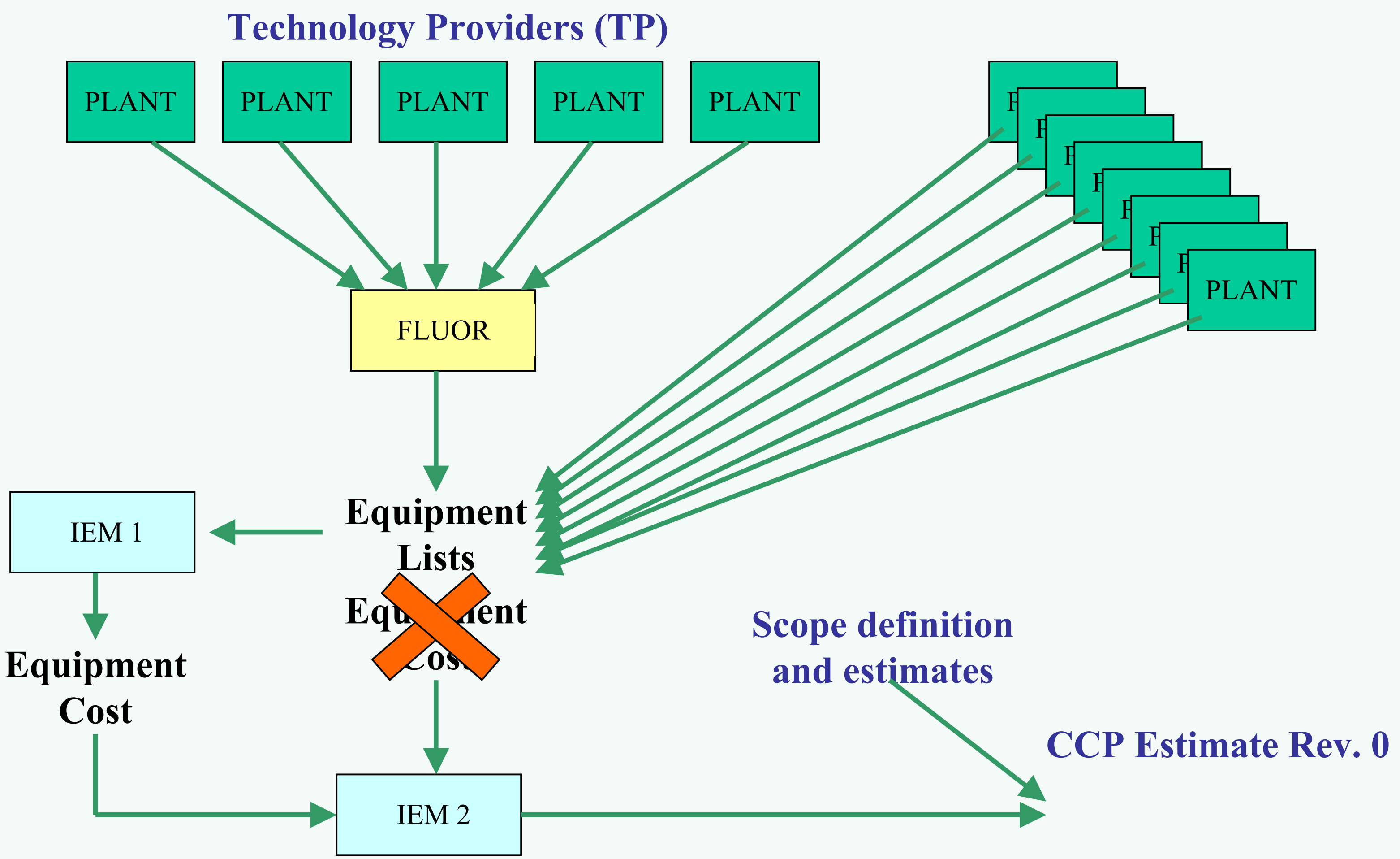
Two Internal Estimation Models (IEM) Applied

IEM1	{	Equipment Cost
	{	/
	{	Equipment Material Factor
	{	=
	{	Equipment Cost (Carbon Steel)
		*
IEM2	{	Factors
	{	=
	{	Total Installed Cost (TIC_1) – Base Estimate
	{	*
	{	Contingency (here: factor equal to 1.2)
	{	=
	{	Total Installed Cost (TIC_2) – 50/50-estimate

Procedure to Calibrate against Fluor Baselines and Apply the "Factor Cost" Model (IEM 2)

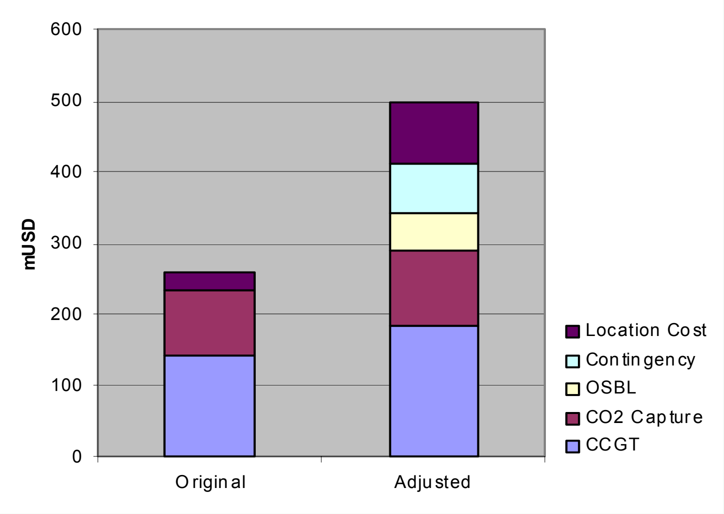


Equipment Costs Estimation (if needed)



CCP Revision of TP Estimates

[MUSD]	"Basis" Nexant	CCP	Comments
CCGT, IBL	144.0	183.3	CCP Generic turn key figure excl. cont.: 464 USD/kW
CCGT, OBL		53.8	Total local cost 75 MUSD, ref. Fluor HMR - plus First Fills
Amine Absorption	66.0	73.4	CCP estimate: 30% higher equipment cost than Nexant
CO2 Compression	25.4	33.3	CCP estimate: 30% higher equipment cost than Nexant
Total Generic Excl. Contingency	**235.4**	**343.8**	
Contingency		68.8	Nexant has not included contingency
Total Generic Cost	**235.4**	**412.5**	
Local Add-on	22.9	86.9	CCP's add-on for Norway (compared to generic): 1.21
Total Local Cost	**258.3**	**499.4**	



CCP Baseline Scenarios

Scenario	Fuel	CO_2 Source	CO_2 Sink	Capture Target (MM tonne/yr)
Grangemouth Refinery in Scotland	Gas and Fuel Oil	Flue gas from heaters and boilers	Offshore EOR	2.0
Norway 385-MW power plant in Karsto, Norway	Gas	Flue gas from turbine outlet	Offshore EOR	1.1
Alaska Eleven 30-MW single cycle gas turbines.	Gas	Flue gas from distributed turbines	Onshore EOR	1.8
Canada Gasification plant	Pet Coke	Syngas from gasifier	Onshore EOR	6.8

Each technology was evaluated in one or more scenarios.

The Matrix: Cost Estimates 2003

Case	Scenario				Process Group			Technical Provider	Contractor
	N	U	A	C	Po	Pr	Ox		
Uncontrolled	x							Norsk Hydro	(CCP)
				x				Fluor	Fluor
Baseline Amine	x				x			Fluor	Fluor
		x			x			Fluor	Fluor
			x		x			Fluor	Fluor
Baseline Gasification				x	x			Fluor	Fluor
Very Large Scale ATR			x			x		Jacobs	(CCP)
Membrane WGS (DOE)		x				x		Eltron Res., SOFCo	Fluor
Membrane WGS (GRACE)		x				x		BP	(CCP)
Hydrogen Membrane Reformer	x					x		Norsk Hydro	Fluor
Sorption Enhanced WGS			x			x		Air Products	Fluor
Sorption Enhanced WGS - O_2	x					x		Air Products	(CCP)
Sorption Enhanced WGS - Air	x					x		Air Products	(CCP)
Advanced Gasification				x		x		Fluor	Fluor
Flue Gas Recycle ASU		x					x	Air Products	Air Products
Flue Gas Recycle ITM		x					x	Air Products	Air Products
Amine – Normal Cost	x				x			Nexant	Nexant/(CCP)
Amine – Low Cost	x				x			Nexant	Nexant/(CCP)
Amine – Low Cost Integrated	x				x			Nexant	Nexant/(CCP)
Membrane Contactor/KS-1	x					x		Kværner/MHI	Kværner/MHI

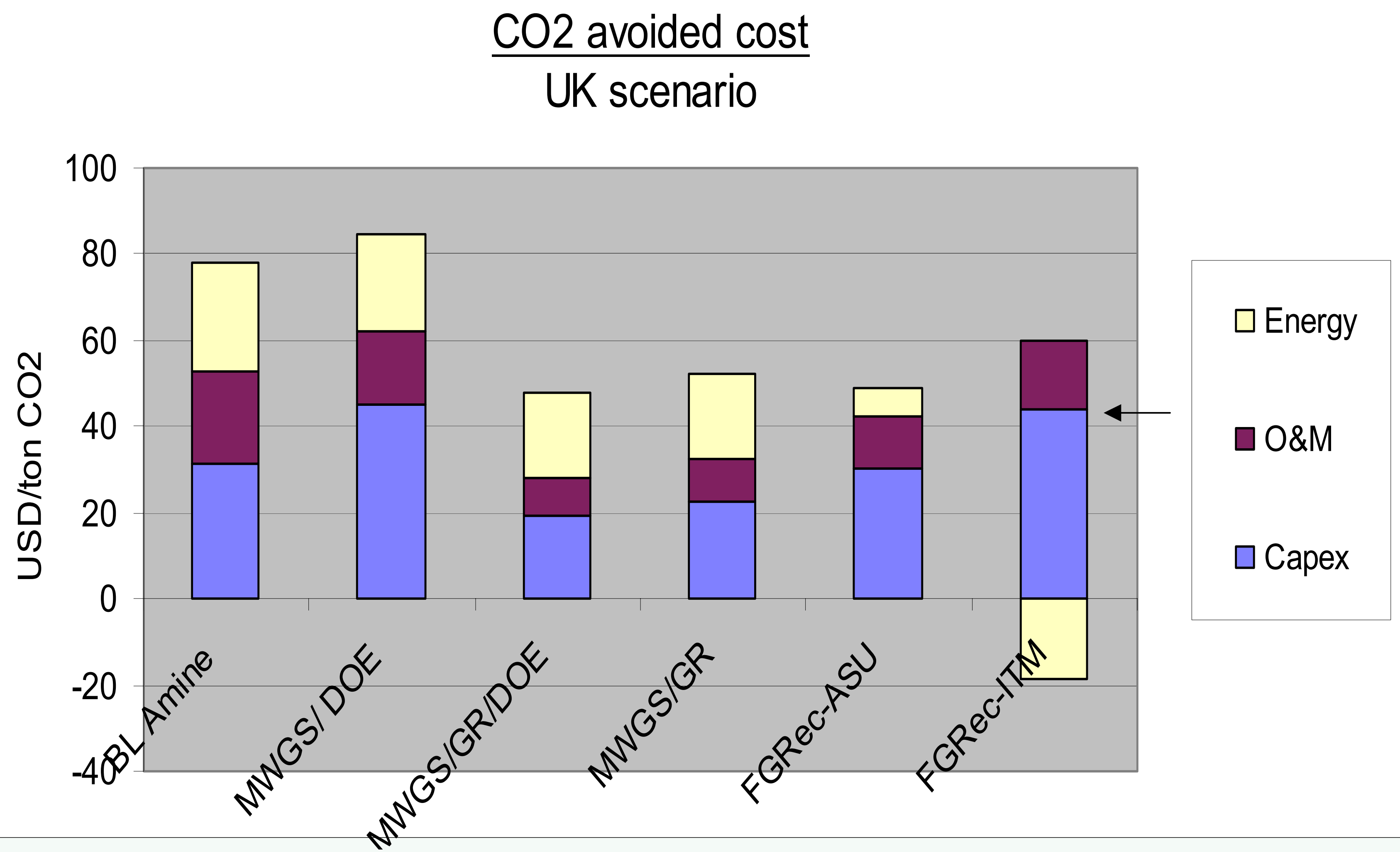
Additional Economic Assumptions

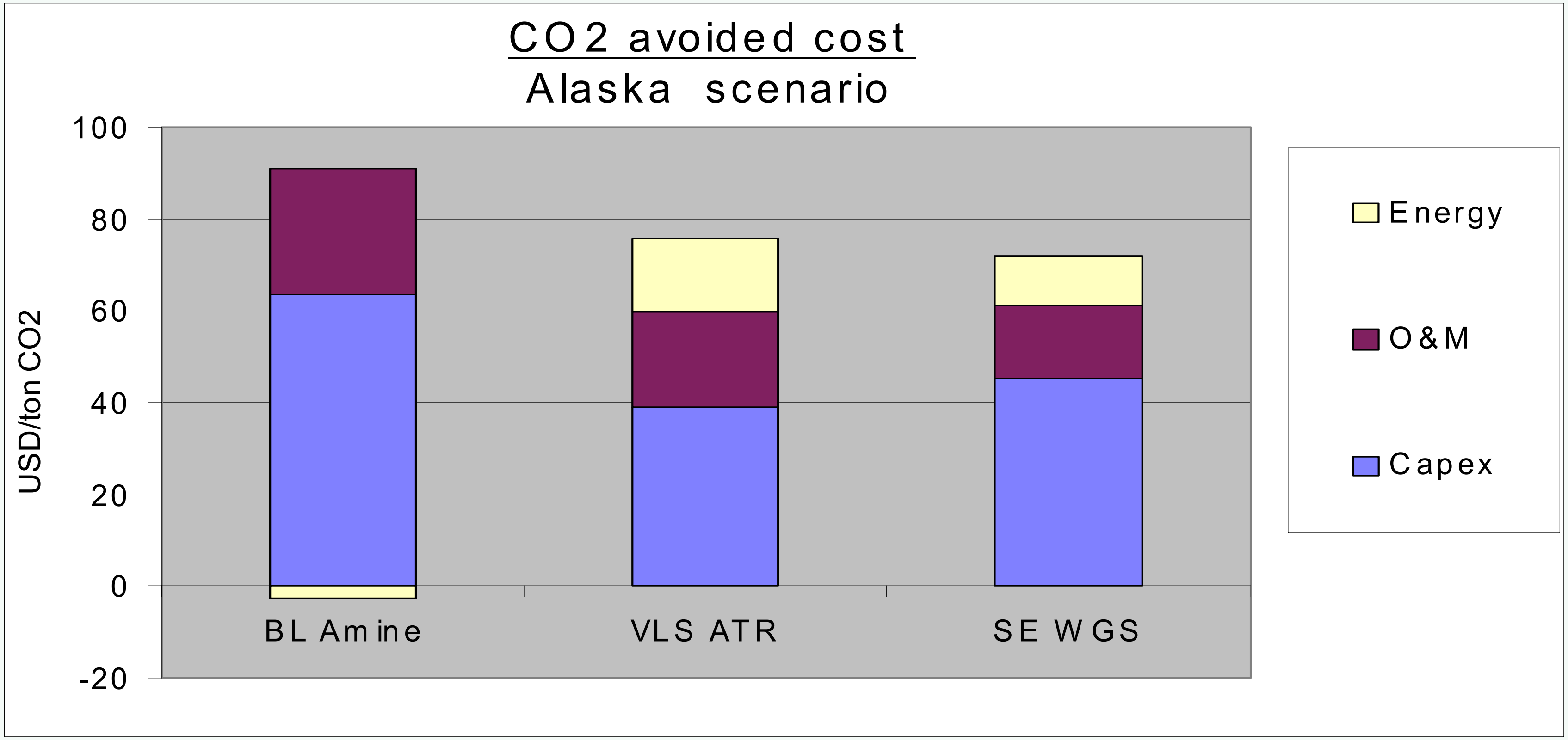
Parameter	Units	Generic	UK	Alaska	Norway	Canada
Natural gas	USD/mBtu	3.0	3.0	0.0	2.0	3.0
Electricity *)	USD/MWh	34	34	0	34	34
Coal/ coke	USD/ton	30	-	-	-	0
CO2	USD/ton	20				
NOx	USD/ton	2500				
SO2	USD/ton	200				
Discount factor	Real rate	10 %				
Annual capital charge factor		-> 11,02% at 25 yr lifetime				

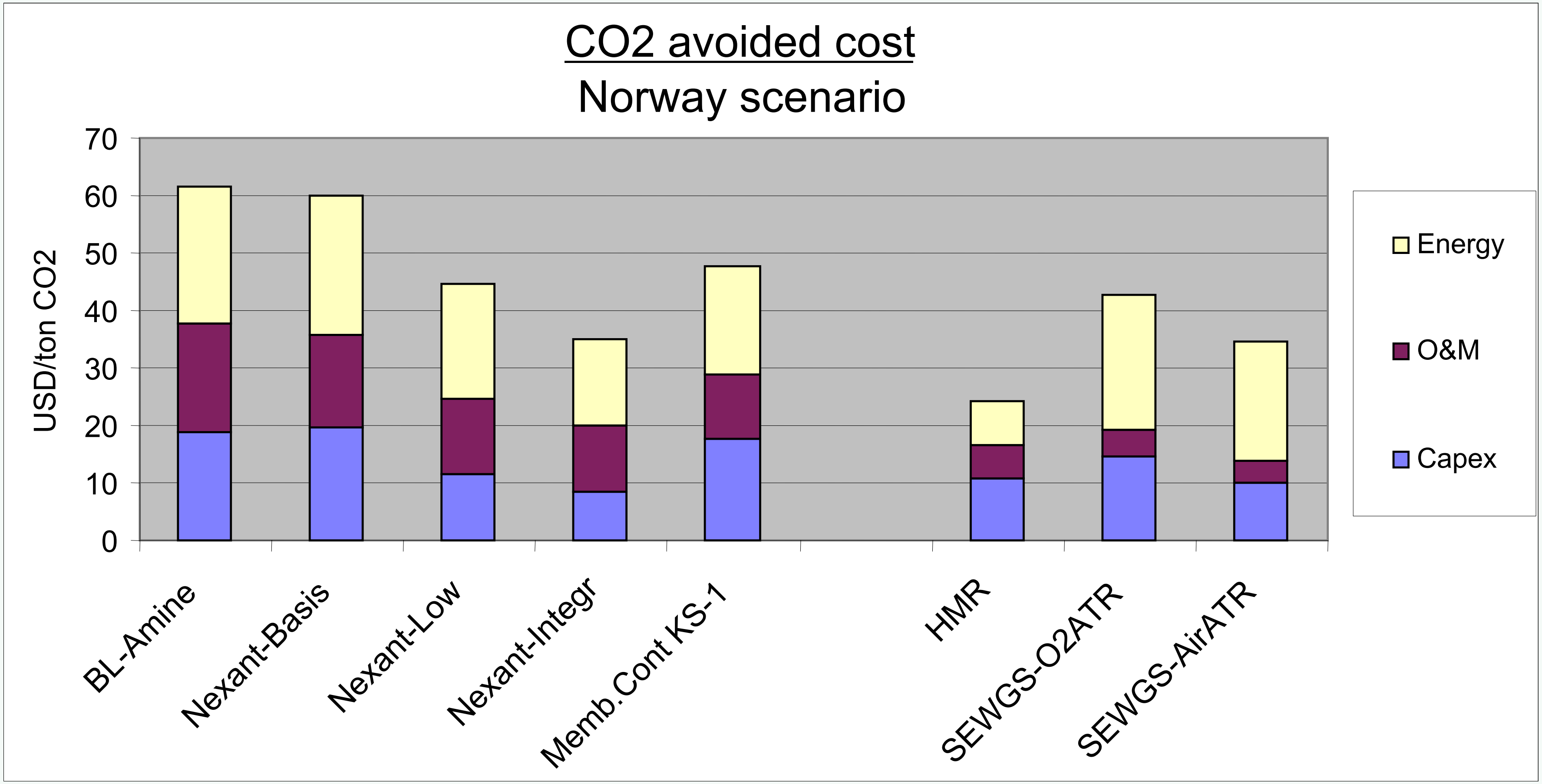
*) = base case uncontr. CCGT-powergen-cost

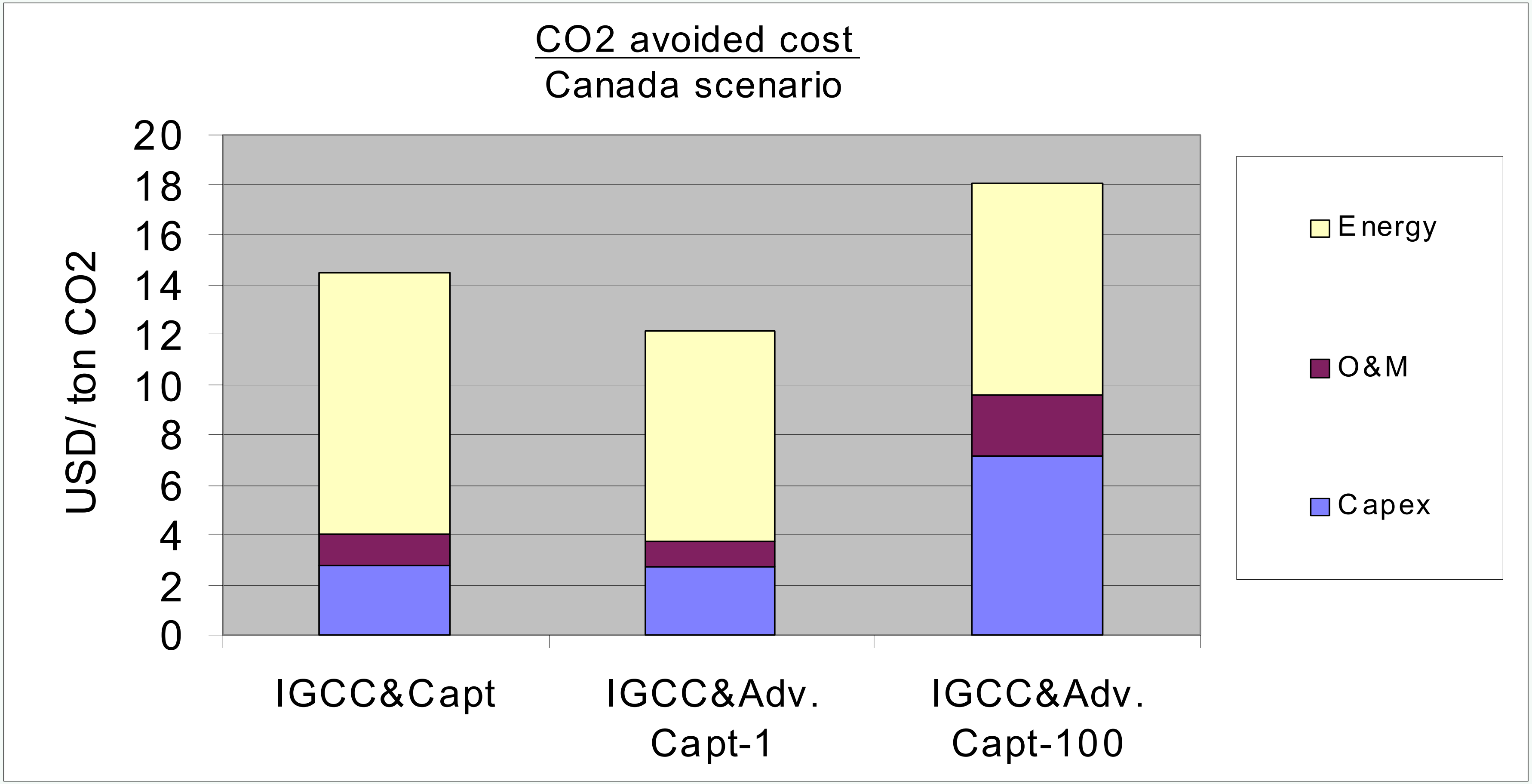
Investment and O&M Costs

		Generic		Local	
Scenario	**Case**	**Investment**	**O&M** [1)]	**Investment**	**O&M** [1)]
Norway	Uncontrolled	284	13	333	15
	Baseline Amine	407	26	489	30
	Membrane Contactor/KS-1	405	22	487	25
	Hydrogen Membrane Reformer	390	21	453	23
	Sorption Enhanced WGS O2	420	21	496	24
	Sorption Enhanced WGS Air	476	24	562	27
	Amine Normal Cost	413	25	500	28
	Amine Low Cost	363	22	435	25
	Amine Low Cost Integrated	346	23	413	25
UK	Baseline Amine	362	27	424	29
	Membrane Water Gas Shift (DOE)	524	24	610	27
	Membrane Water Gas Shift (GRACE)	235	14	275	15
	MWGS (GRACE) with DOE Membrane	199	12	233	14
	Flue Gas Recycle ASU	428	21	486	23
	Flue Gas Recycle ITM	485	21	546	24
Alaska	Baseline Amine	1017	49	1479	67
	Very Large Scale ATR	826	44	1139	57
	Sorption Enhanced WGS	726	32	1020	44
Canada	Uncontrolled	799	36	906	41
	Baseline Gasification	1305	61	1478	67
	Advanced Gasification I	1305	59	1468	66
	Advanced Gasification II	1480	66	1656	73

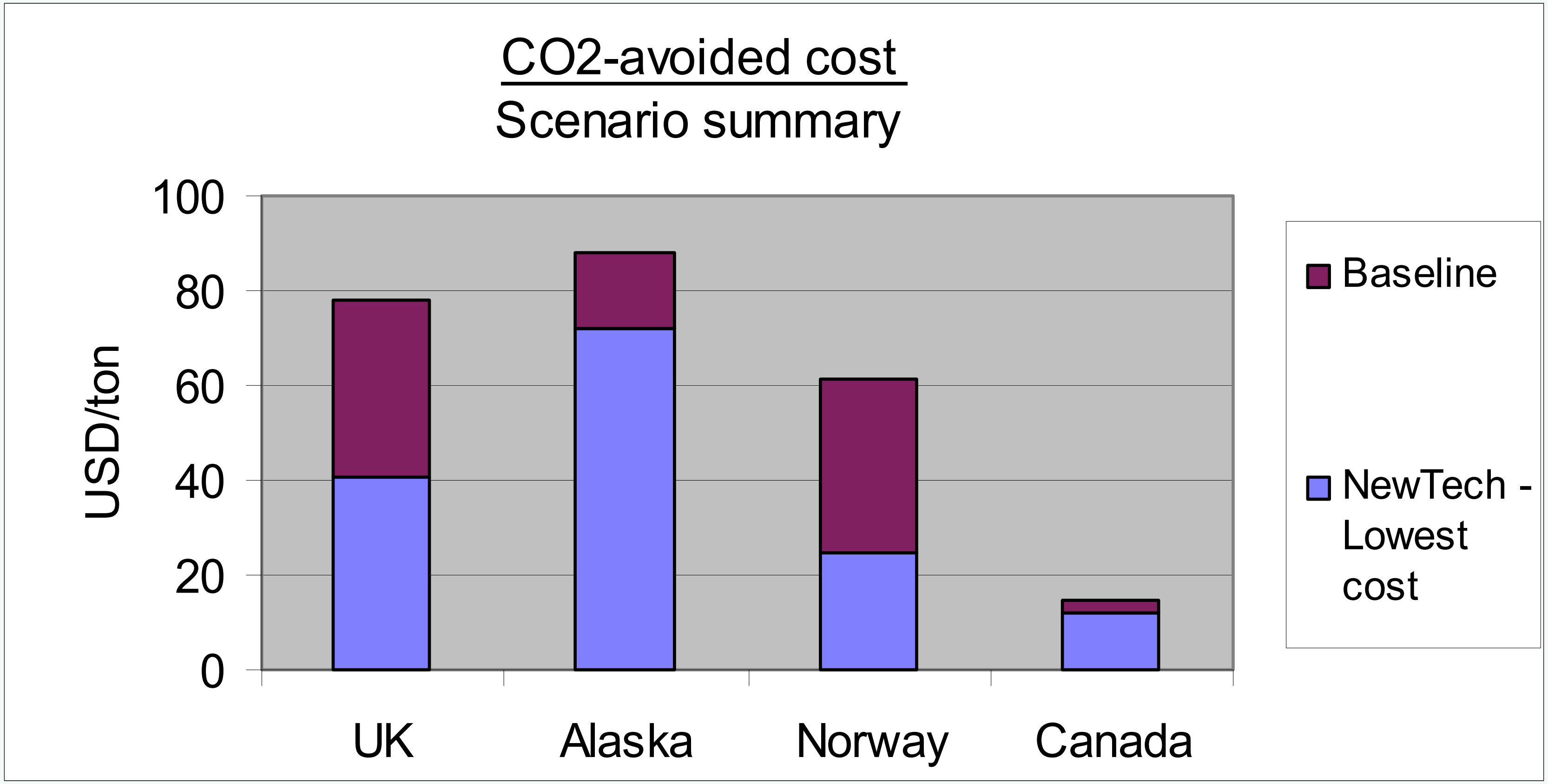

CO2 avoided cost
UK scenario
USD/ton CO2
100
80
60
40
20
0
-20
-40
BL Amine
MWGS/ DOE
MWGS/GR/DOE
MWGS/GR
FGRec-ASU
FGRec-ITM
Energy
O&M
Capex


CO2 avoided cost
Alaska scenario
USD/ton CO2
100
80
60
40
20
0
-20
BL Amine
VLS ATR
SE WGS
Energy
O&M
Capex


CO2 avoided cost
Norway scenario
USD/ton CO2
70
60
50
40
30
20
10
0
BL-Amine
Nexant-Basis
Nexant-Low
Nexant-Integr
Memb.Cont KS-1
HMR
SEWGS-O2ATR
SEWGS-AirATR
Energy
O&M
Capex


CO2 avoided cost
Canada scenario
USD/ ton CO2
20
18
16
14
12
10
8
6
4
2
0
IGCC&Capt
IGCC&Adv. Capt-1
IGCC&Adv. Capt-100
Energy
O&M
Capex

CO_2 Capture Project



Economic Analysis

Grangemouth UK refinery scenario

Capture technology	Area	CO2 avoided costs, $/ton	% reduction
Baseline	Post	79.8	0
MWGS - Eltron	Pre	N/A	N/A
MWGS - Sintef	Pre	N/A	N/A
Flue gas recycle w/ ASU	Oxy	49.6	38
Flue gas recycle w/ ITM	Oxy	56.9	29

Economic Analysis

Alaska gas turbine scenario

Capture technology	Area	CO2 avoided costs, $/ton	% reduction
Baseline	Post	88.2	
Very large scale ATR	Pre	76.0	14
SEWGS	Pre	71.8	19

Economic Analysis

Norway power plant scenario

Capture technology	Area	CO2 avoided costs, $/ton	% reduction
Baseline	Post	61.6	0
Nexant integrated	Post	35.1	43
MHI-Kvaerner contactor	Post	47.5	23
Membrane reformer	Pre	24.4	60
SEWGS with air ATR	Pre	34.4	44

Economic Analysis

Canadian scenario

Capture technology	Area	CO2 avoided costs, $/ton	% reduction
Baseline	Pre	14.5	0
Fluor CO2LDSEP	Pre	12.2	16

Production of syngas is part of baseline scenario. Removal of CO2 from syngas is relatively inexpensive.

Recap of Capture Conclusions

Key Findings and Conclusions

Post combustion

- Cost reductions of 25-43% over BAT at the start of the CCP are reported
- $35/t CO_2 avoided is now considered possible
- There is the potential for further cost reductions through process integration and advanced solvents

Key Findings and Conclusions (cont'd)

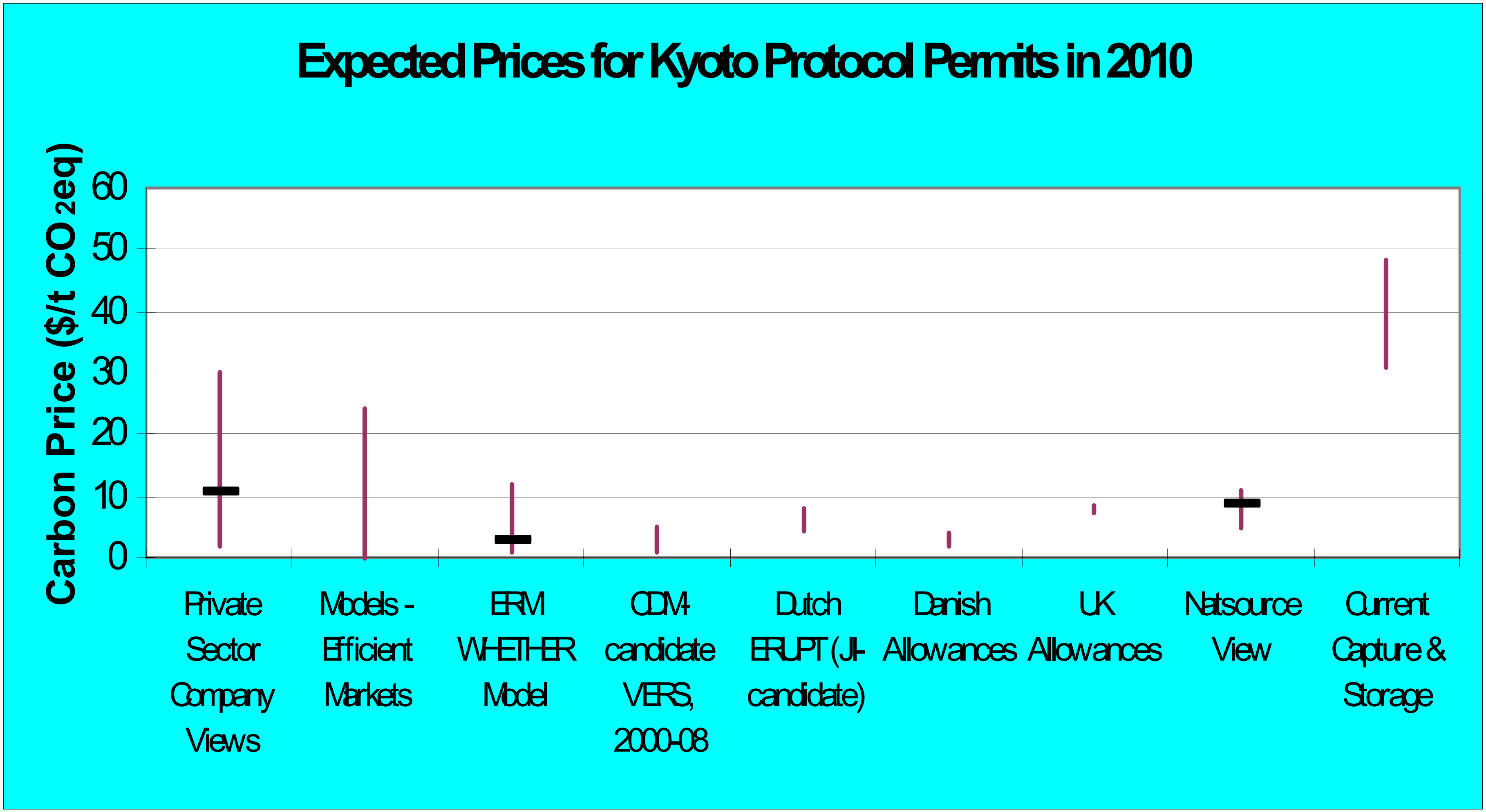
Advanced Pre-combustion

- Cost reductions of 55% over BAT at the start of the CCP are reported
- \$15/t CO_2 avoided is possible when combining IGCC with the new CCP technologies developed
- Process step reduction and H_2 membranes offer significant capital cost reductions and further potential for reducing CO_2 avoided cost

Key Findings and Conclusions (cont'd)

Oxyfiring

- Cost reductions of 40%+ over BAT at the start of the CCP are reported
- $30/t CO_2 avoided is now considered possible through application of state of the art technology with heaters and boilers


Expected Prices for Kyoto Protocol Permits in 2010
Carbon Price ($/t CO2eq)
0
10
20
30
40
50
60
Private Sector Company Views
Models - Efficient Markets
ERM WHETHER Model
CDM-candidate VERS, 2000-08
Dutch ERUPT (JI-candidate)
Danish Allowances
UK Allowances
Natsource View
Current Capture & Storage

Key findings/Conclusions Cont'd

- Previous slide illustrates the likely mismatch between CO2 costs/credits and the cost of capture and storage, indicating that although a sharp reduction in CO2 capture costs has been obtained by the CCP, more needs to be done to facilitate the economic use of capture and storage on a significant scale.
- Additional sources of value, such as Enhanced Oil Recovery, can help to bridge this gap.

Key Findings and Conclusions (cont'd)

CCP has developed an economic evaluation tool that provides a consistent and transparent method to evaluate the cost of different capture technologies and compare costs between different projects.