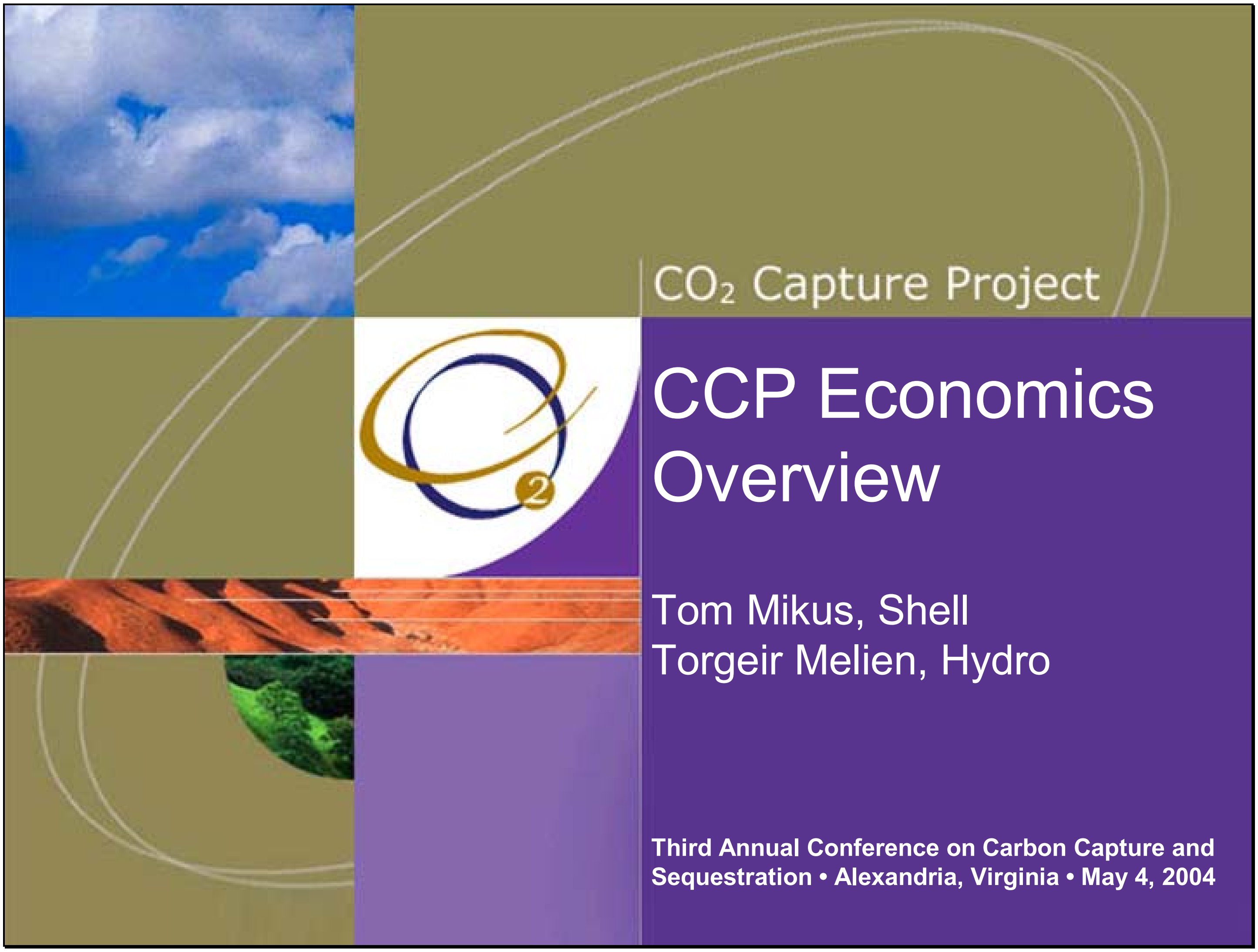
CO2 Capture Project
CCP Economics Overview
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Torgeir Melien, Hydro
Third Annual Conference on Carbon Capture and Sequestration • Alexandria, Virginia • May 4, 2004

CO₂ Capture Project

Final Cost Estimates and Economics

- Motivation and background
  - Objectives and targets
  - Work program 2000-2004
- Approach and challenges
  - Scenarios and technologies
  - Baseline technologies and new technologies
  - Cost estimation and screening
- Results and findings
  - CO_2 costs

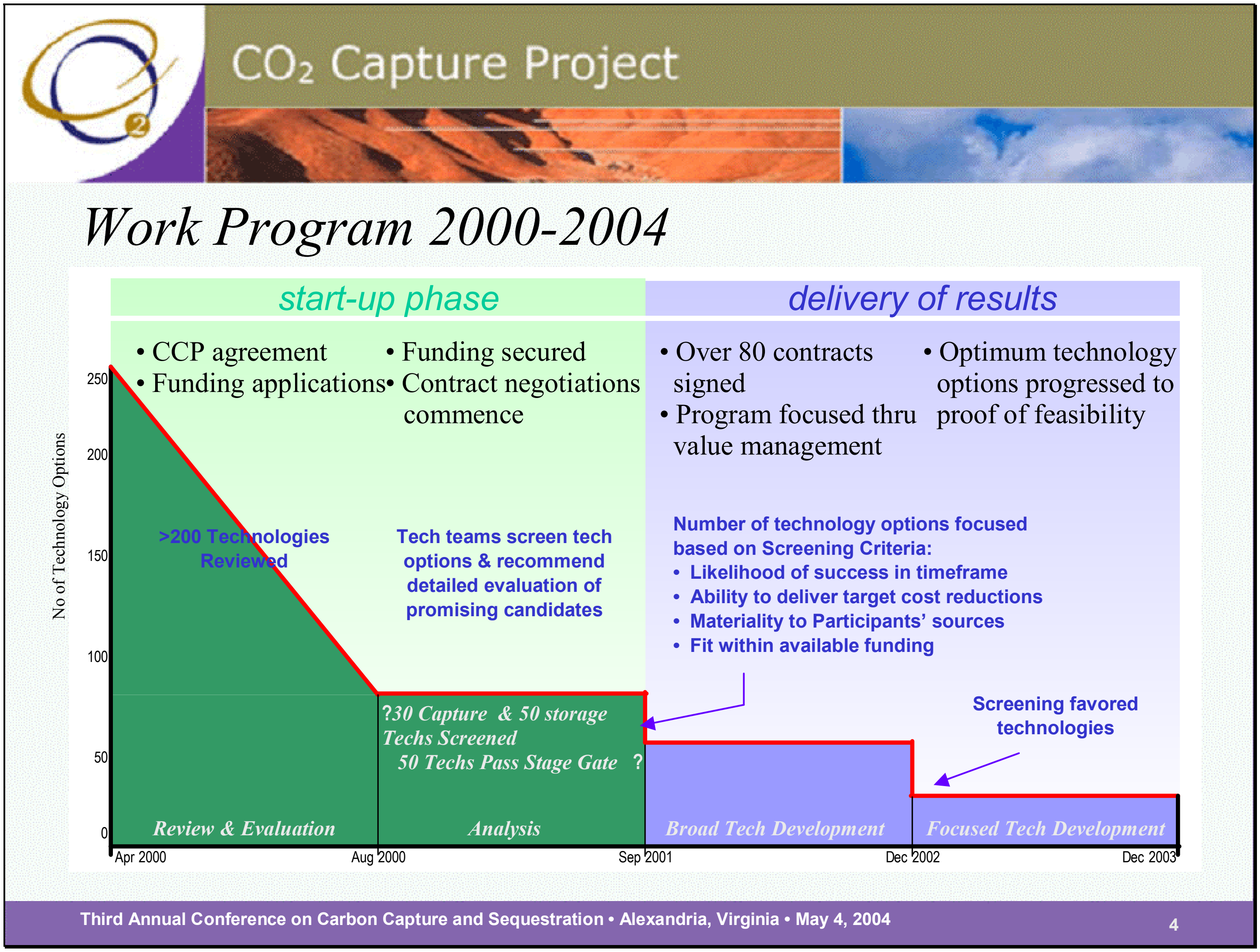
Slide 3

Objectives and Targets

- Develop new more-efficient CO_2-capture technologies
- Reduce capture cost 50 to 75%

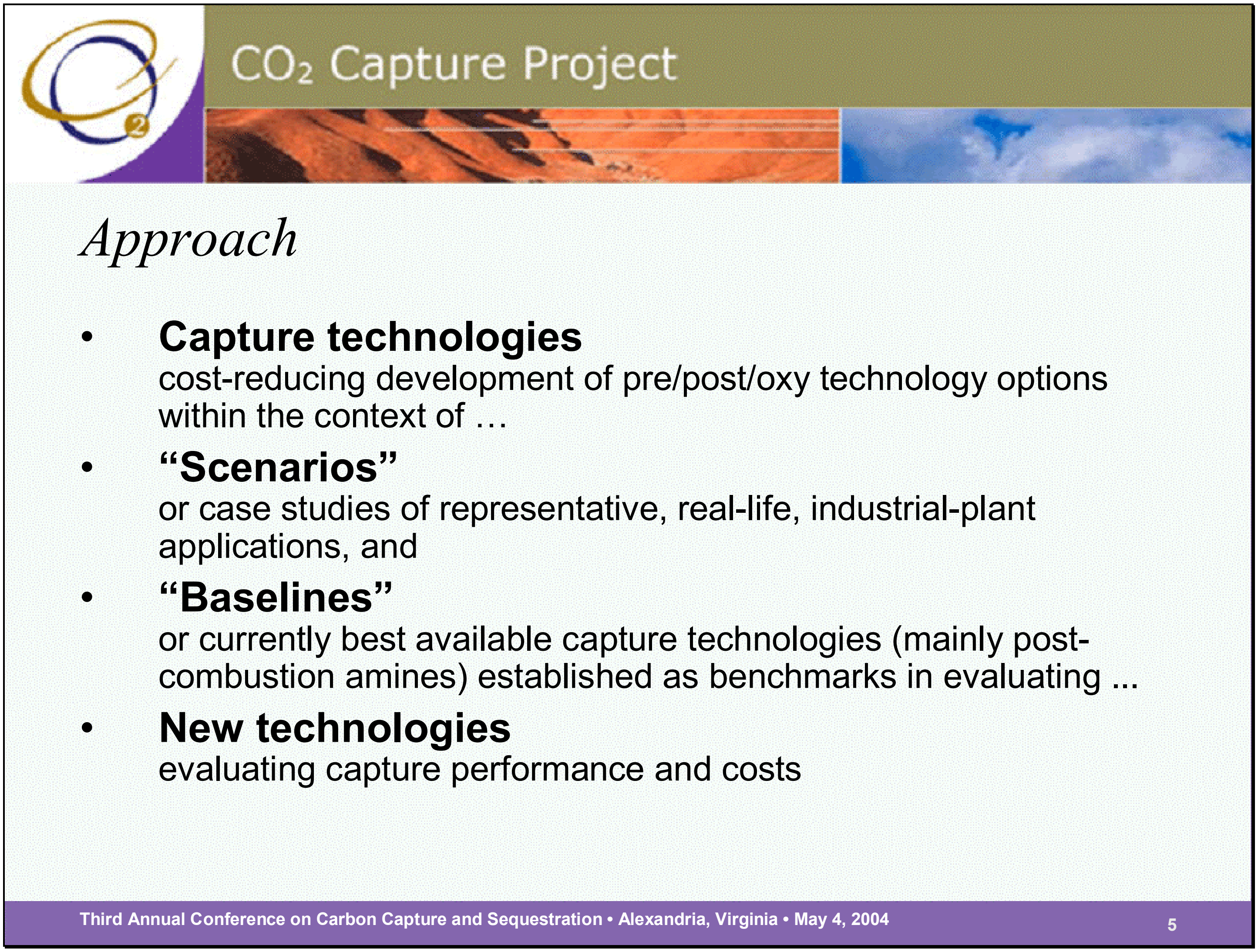
Main CCP objective is to further develop existing and new, more cost- effective CO2 capture technologies to a ”proof of concept / feasibility” stage. Cost reduction targets are established relative to current Baseline/ BAT –technologies, set to 50% for retrofit and 75% for new-build cases, measured in terms of USD per ton CO2 emissions avoided.

Slide 4



The slide illustrates the overall CCP-1 program content and timeline.

Slide 5



The 4 terms on this slide have been central in CCP’s approach:
The CO2-capture technologies, being our main development focus, are evaluated in the context of what we call ”scenarios”, or real-life case studies of applications to CO2-emitting industrial plants. As benchmarks for all new technologies, a ”baseline” (or BAT) capture technology is established for all scenarios. In 3 of the 4 scenarios the post-combustion MEA amine-technology is applied. In the gasification scenario a pre-combustion capture scheme is applied.

Slide 6

CO_2 Capture Project

CCP Scenarios

Scenario	**Fuel Source**	**CO_2 Source**	**Geologic Sink**	**Location**
Refinery	Hydrocarbon Gas + Liquids	Heaters and Boilers	Storage	**UK** Scotland
Large Gas Turbines	Natural Gas	Large Electric Power (CCGT)	Storage	Western **Norway**
Distributed Gas Turbines	Natural Gas	Small Distributed Turbines	Storage	**Alaska** North Slope
Gasification	Solid Gasification (pet coke)	Steam, H_2, and Electric Cogen	Storage	Western **Canada**

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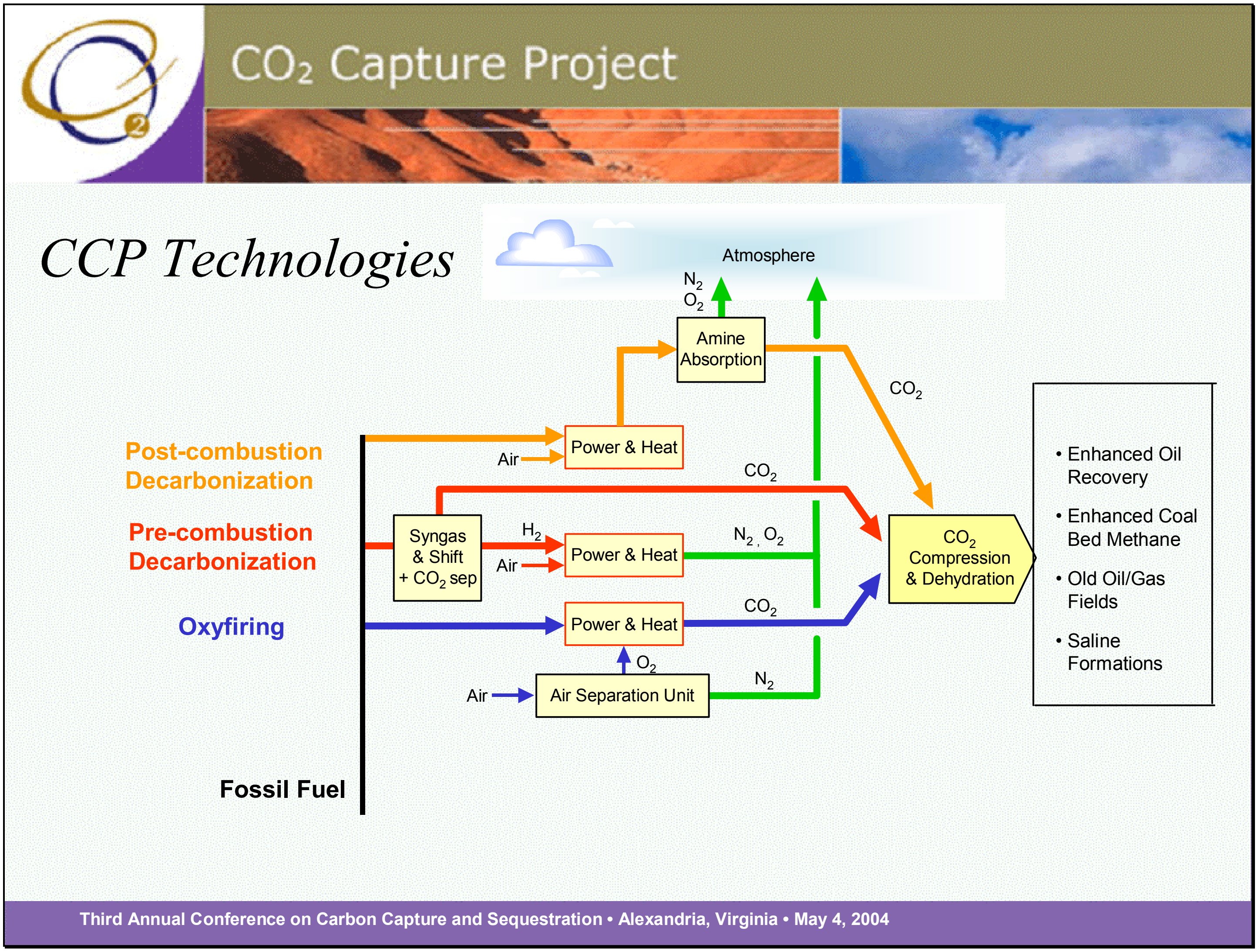
These 4 industrial plant scenarios in UK, Norway, Alaska and Canada were established at an early stage as representative ”testing arenas” for new capture technology concepts. The scenarios cover different plant types, geographical locations, fossil fuels and CO2 sources. They also cover the retrofit- and newbuild dimension, since two are existing plants, while two are planned, non-built plants.

Slide 7



This slide sketches the three principal CO2-capture routes; post-combustion, pre-combustion and oxyfiring capture.

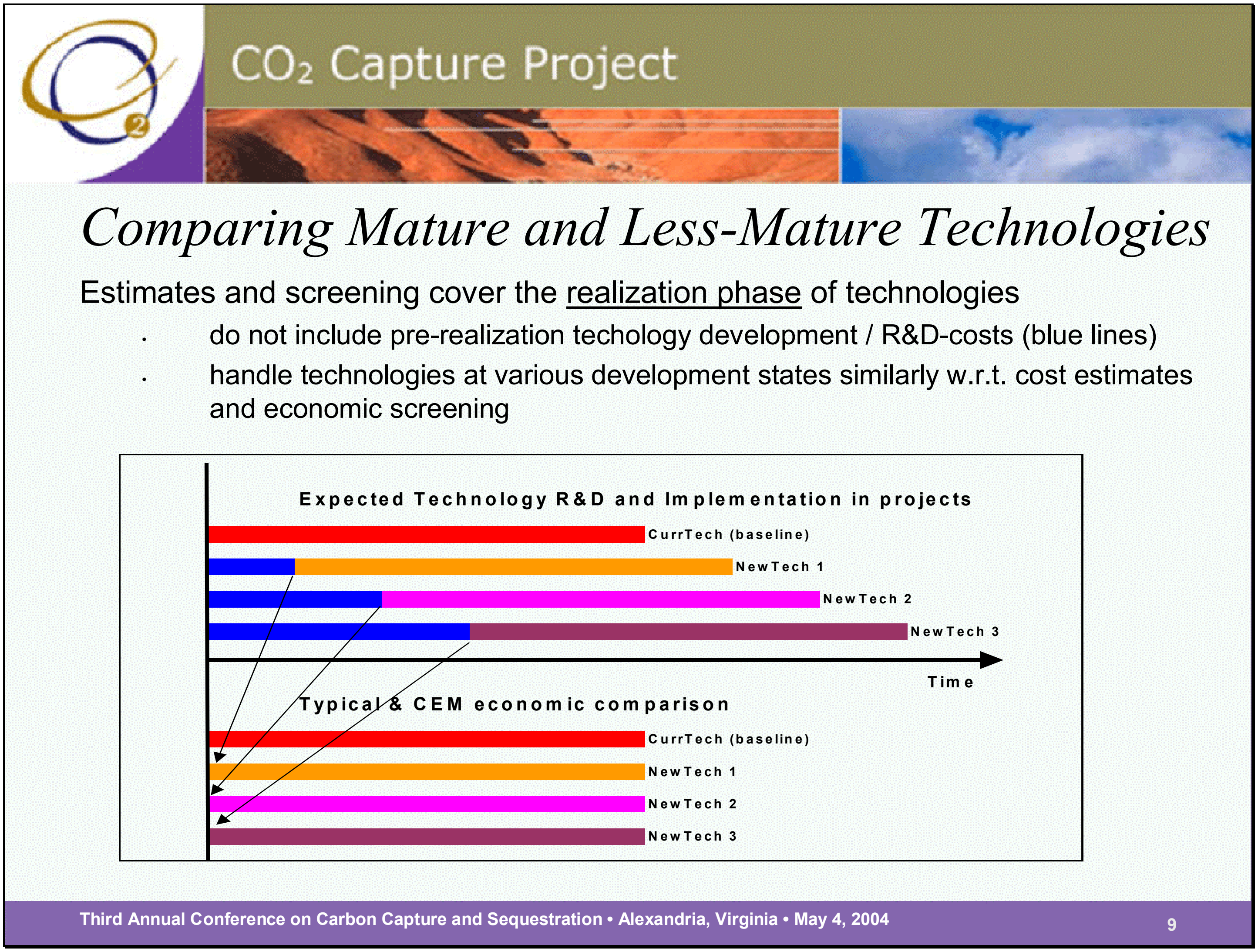
CO2 Capture Project

Final Scenario-Technology Cases

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
				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)
Best Integrated Technology (BIT)	x				x			(Nexant/MHI) CCP	(CCP)
Membrane Contactor/KS1	x					x		Kværner/MHI	Kværner/MHI

N – Norway, U – UK, A – Alaska, C – Canada. Po – Post-Combustion, Pr – Pre-Combustion, Ox – Oxyfuel

This table summarizes the final matrix of favored Scenario-Technology combinations / cases, including technology providers and contractors.



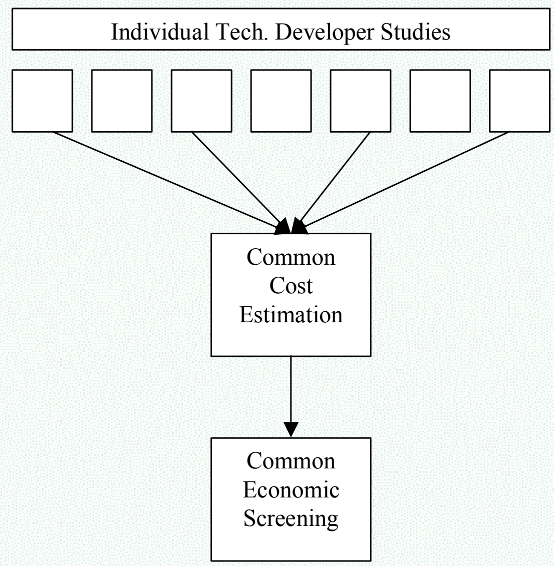
A basic challenge in screening of <u>developing</u> technologies is to compare technologies at different levels of maturity. The upper part of the graph illustrates the varying development periods (blue lines) that one would expect before each technology potentially reach a commercial stage. However, in the quantitative screening work we have focused on the ”realization phase” of the technologies, with the objective to describe their expected costs and performances under future operations, as if they were commercially available.

CO₂ Capture Project

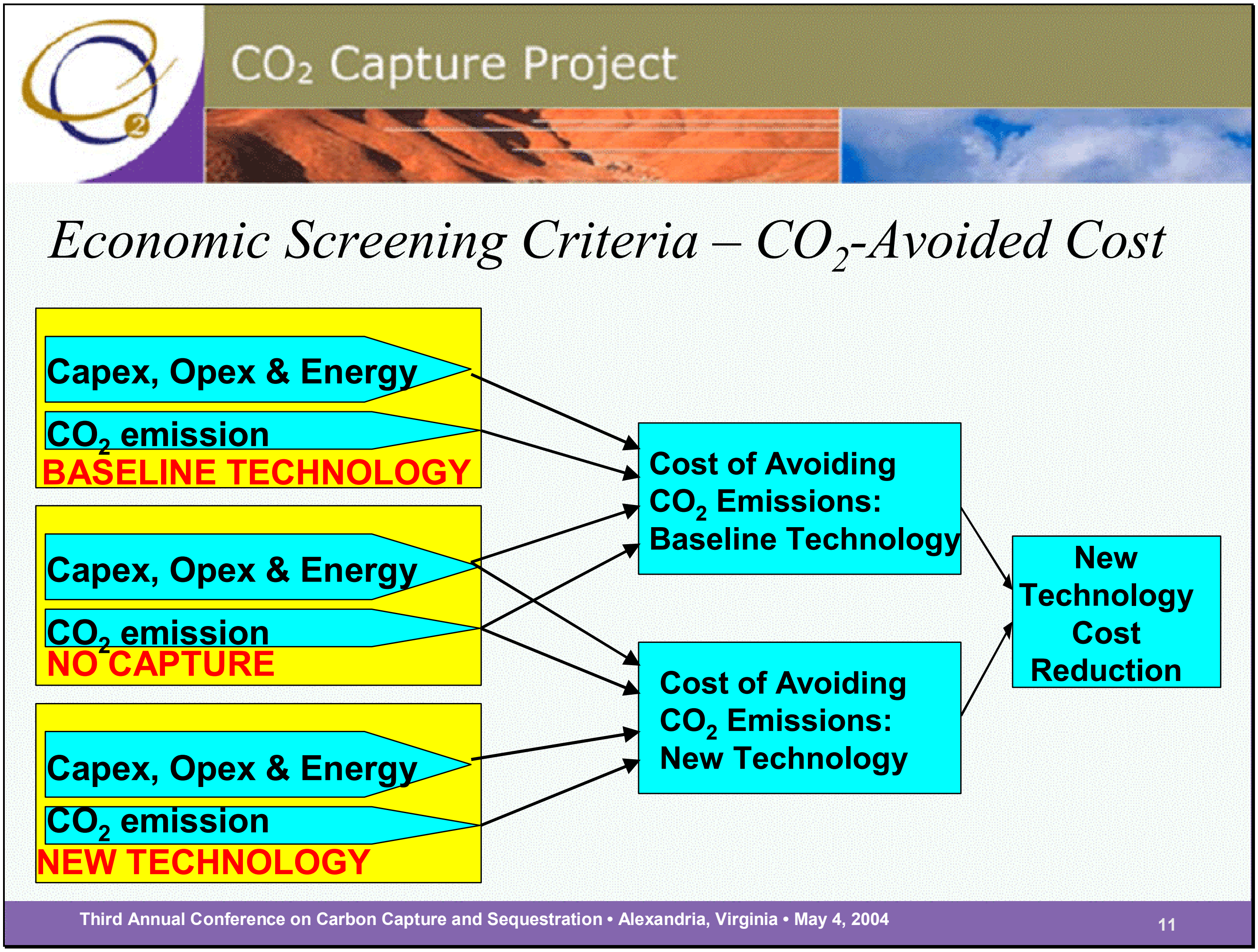
Consistency in Estimation and Screening

Transforming a multitude of individual technology studies into a comparable and quantified set of Scenario/Technology options

- Integrating capture technologies into scenarios
- Calibrating physical scopes and capacities
- Capex vs. opex tradeoffs
- Capex and opex estimation methods and assumptions
- Consistent CO_2-cost evaluation

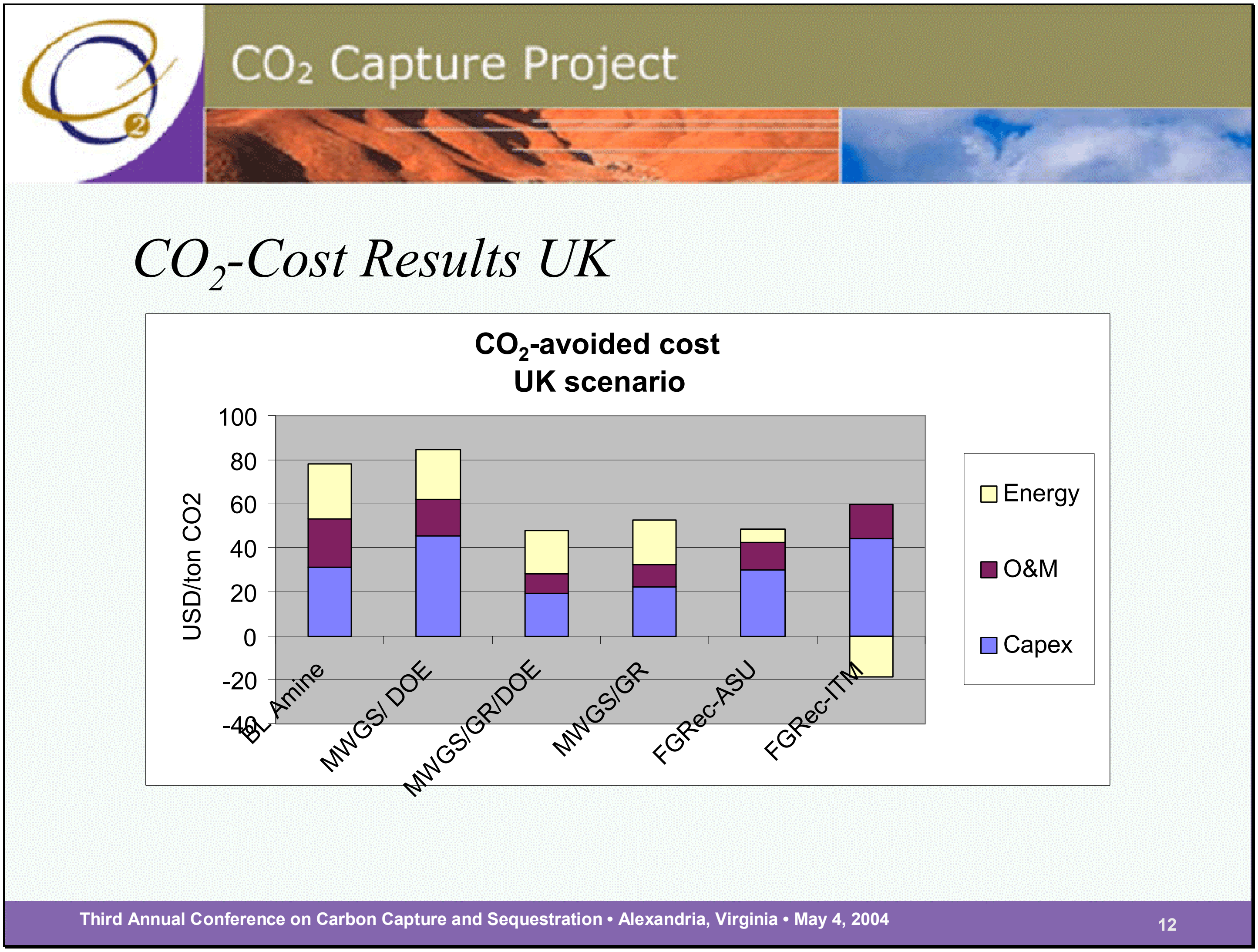


The screening work in CCP is much more than a number of ”stand-alone case-studies”. Our main objective is comparison, screening and eventually technology selection. Our challenge has thus been to describe and quantify all our cases applying a common / consistent set of estimation / screening principles, handling issues as mentioned on the slide.

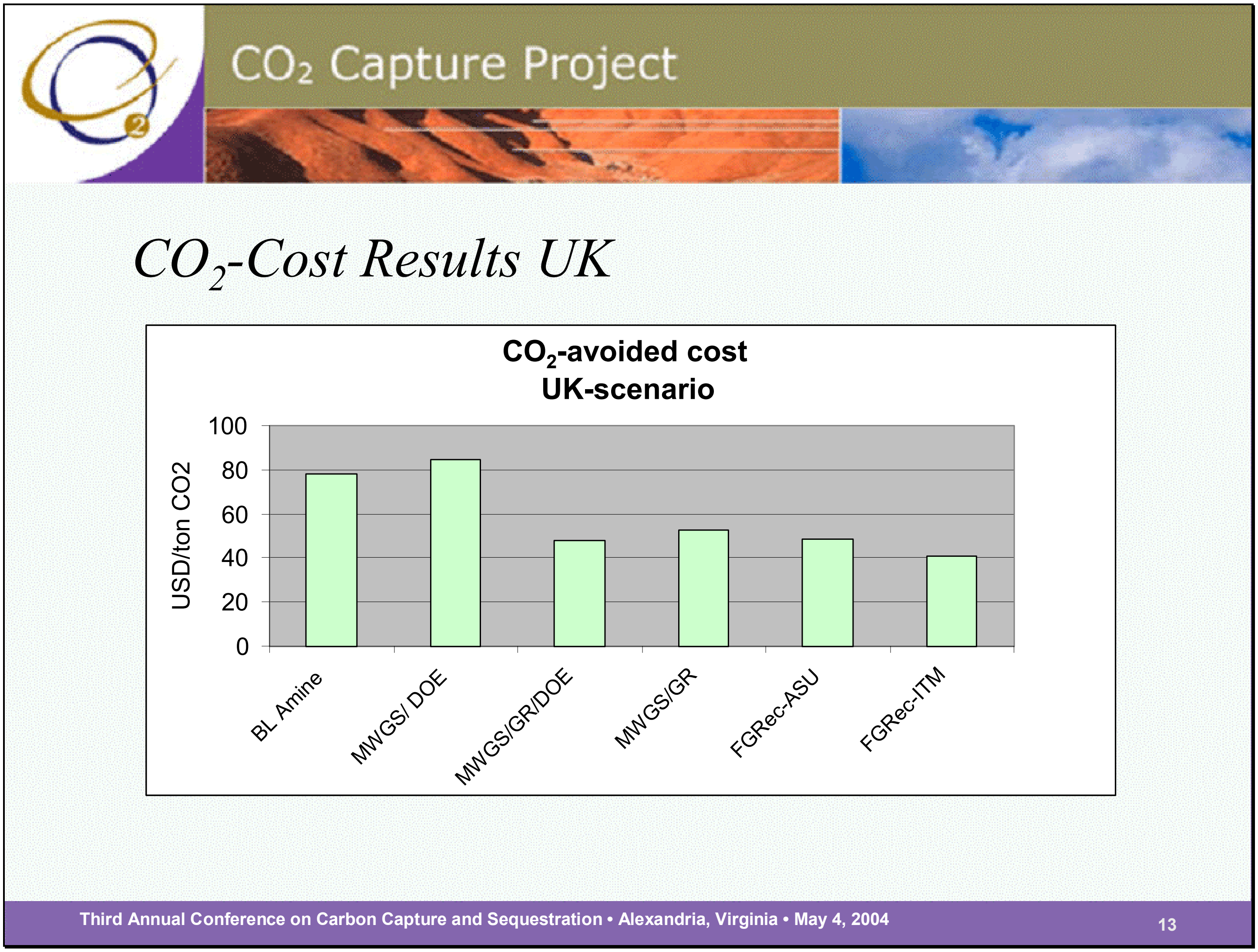


CO2-avoided costs are calculated for all capture technologies by comparing costs and emissions for non-capture (uncontrolled) and capture cases, on a normalized plant-output basis. By comparing Baseline and NewTechnology CO2-avoided costs, percentage cost reductions are calculated.

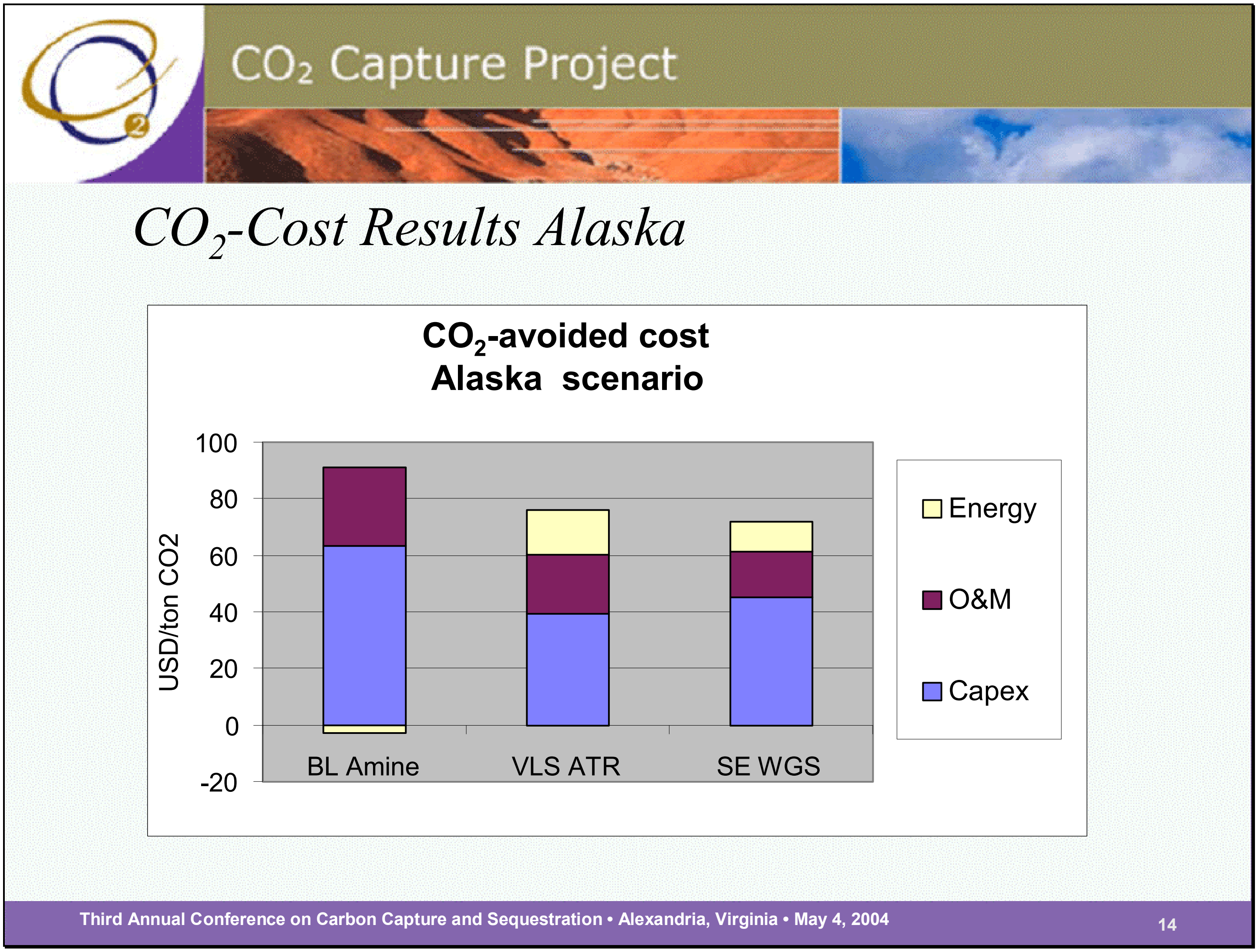
All CO2 costs are calculated at a standardized set of assumptions: pre-tax basis, real discount factor (10%), time horizon (25 yrs) -> capital charge rate (11%) and energy prices; natural gas (3 USD/mBTU), power (34 USD/MWh), and petroleum coke (10 USD/ton).



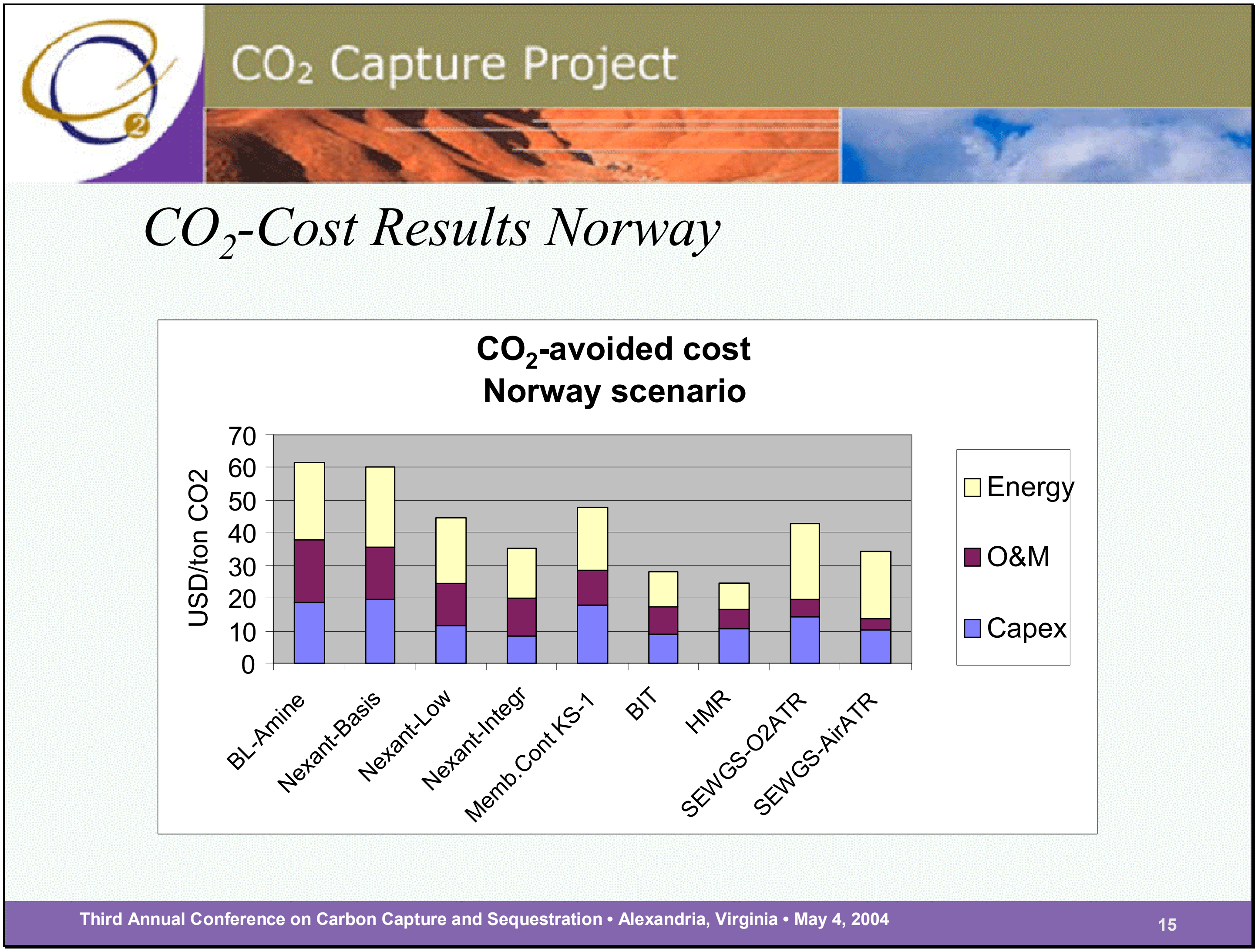
The above calculations indicate a Baseline avoided cost of 78 USD/ton, whereas the Pre-combustion and Oxyfiring cases demonstrate costs of 40-50 USD/ton. The Oxyfiring ITM case is highly energy price sensitive due to the large inherent energy import and export streams (as illustrated in the figure), which easily may be neutralized by alternative energy price assumptions.



Showing the total cost of each technology, including the negative energy cost from the previous slide.



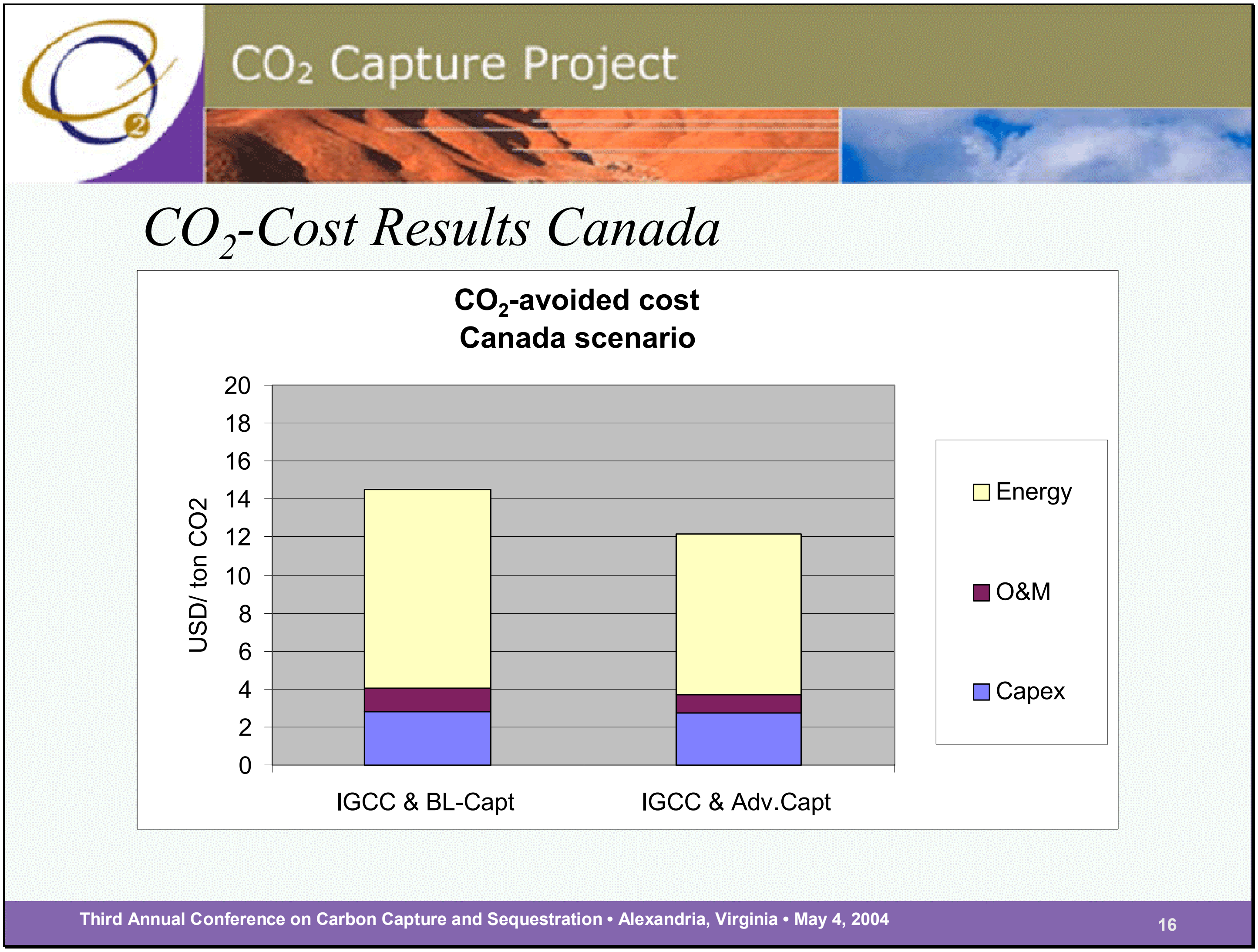
The calculations show avoided costs between 70-90 USD/ton.



The above results indicate significant cost-reduction potential for both the near term and longer term available options:

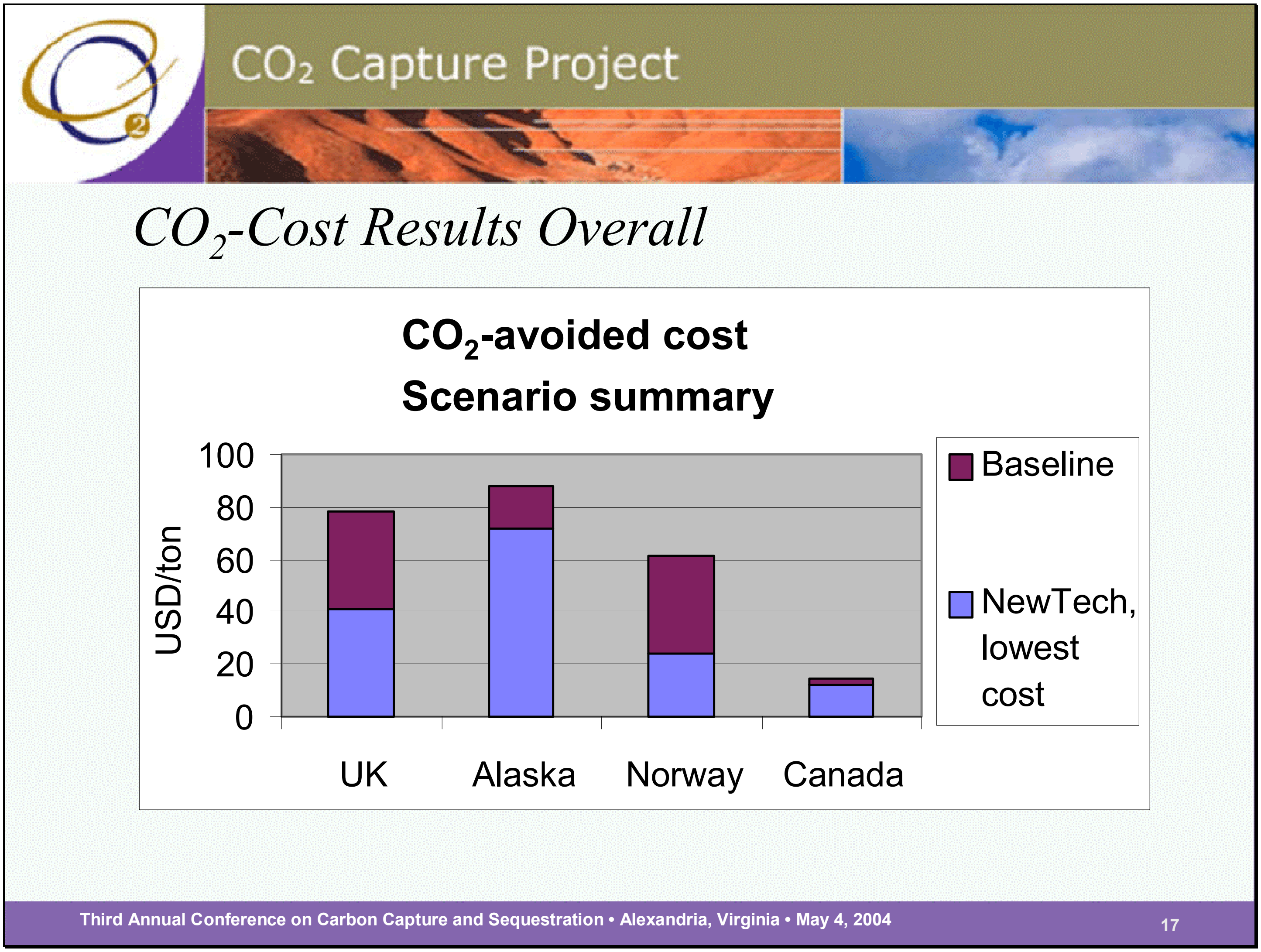
- CO2 costs of existing technologies may be reduced by 30-40% by value engineering and design optimization (ref. the Nexant studies).
- By combining these findings with the MHI-solvent performance, CO2-cost reduction potential above 50% is indicated for the "BIT"-concept.
- An even larger cost reduction potential is indicated for the future pre-combustion HMR technology.

The large reduction potentials above have to be confirmed through further development and verification work.



The low CO2-capture and -avoided costs shown here are mainly due to the fact that the Canadian scenario includes front-end coke gasification systems, and that the syngas production is included both in the uncontrolled and capture cases. The additional CO2 capture units represent thus a smaller capex add-on per ton CO2 handled.

The CO2 cost reduction potential calculated for the advanced capture technology (CO2LDSEP) is 16% on a "best estimate" basis.



By compiling the Baseline and lowest-cost NewTechnology results for each scenario, the identified cost reduction potentials are calculated to:
48% in the UK scenario (oxyfiring route)
19% in the Alaska scenario (pre-combustion route)
60% in the Norway scenario (pre-combustion route)
16% in the Canada scenario (post-combustion approach applied to pre-combustion route)