European Technology Platform for
Zero Emission Fossil Fuel Power Plants (ZEP)

Zero Emission Platform

CO_2 Capture and Storage (CCS) – Matrix of Technologies

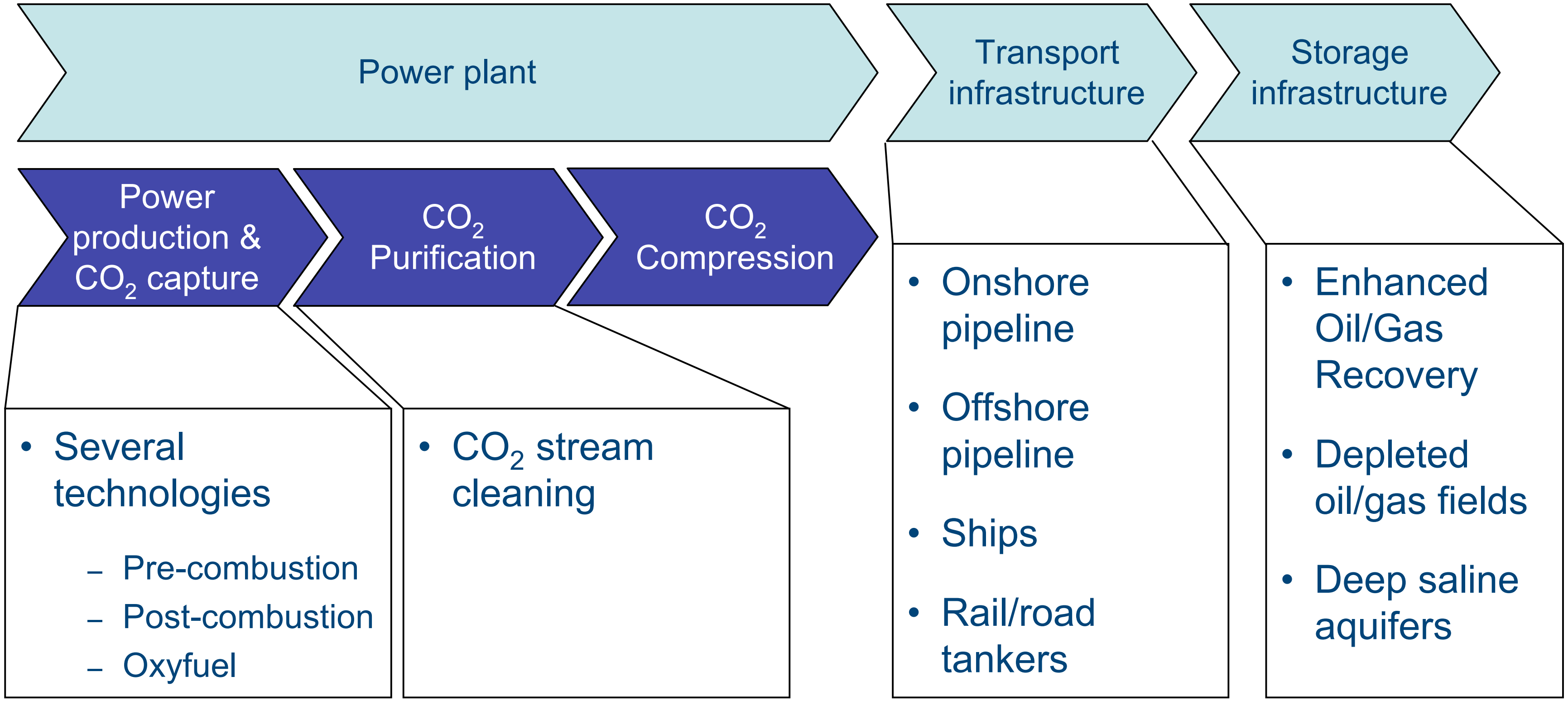
« Technology Blocks »

15 October 2008 FINAL (V9)

Agenda

- Overview of CO_2 value chain
- CO_2 capture technologies
- Efficiency improvement
- Transport & Storage
- Conclusion
- Appendix

CO_2 capture, transport and storage value chain

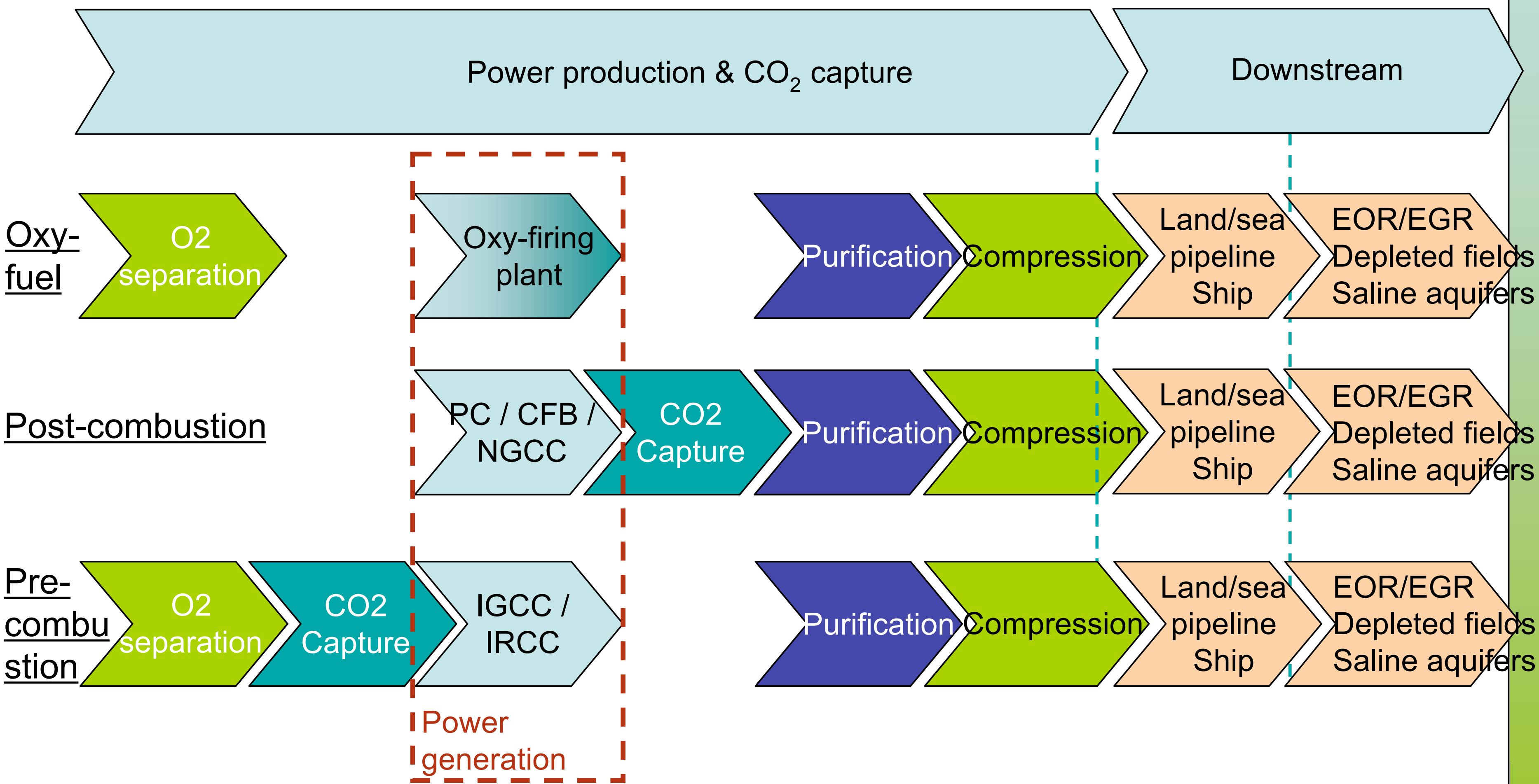


CO_2 capture technology principles

CO_2 capture technologies		CO_2 capture principle	Combustion principle	Power plant definition
Oxyfiring	Coal	High concentration CO_2 stream production	O2 combustion of coal/gas	Oxy-firing plant (Boiler-based)
Post-combustion	Coal	Exhaust gas CO_2 scrubbing	Air combustion of coal/gas	Pulverised Coal (PC) or Circulating Fluidised Bed (CFB)
	Gas			Natural Gas Combined Cycle (NGCC)
Pre-combustion	Coal	Inlet gas CO_2 cleaning	Air combustion of H2	Integrated Gasification Combined Cycle (IGCC)
	Gas			Integrated Reforming Combined Cycle (IRCC)

Note: Coal includes all types of coal and biomass co-firing
Other technologies are not assessed due to low technical maturity or limited market potential (see appendix for details)

CO_2 capture, transport and storage value chains



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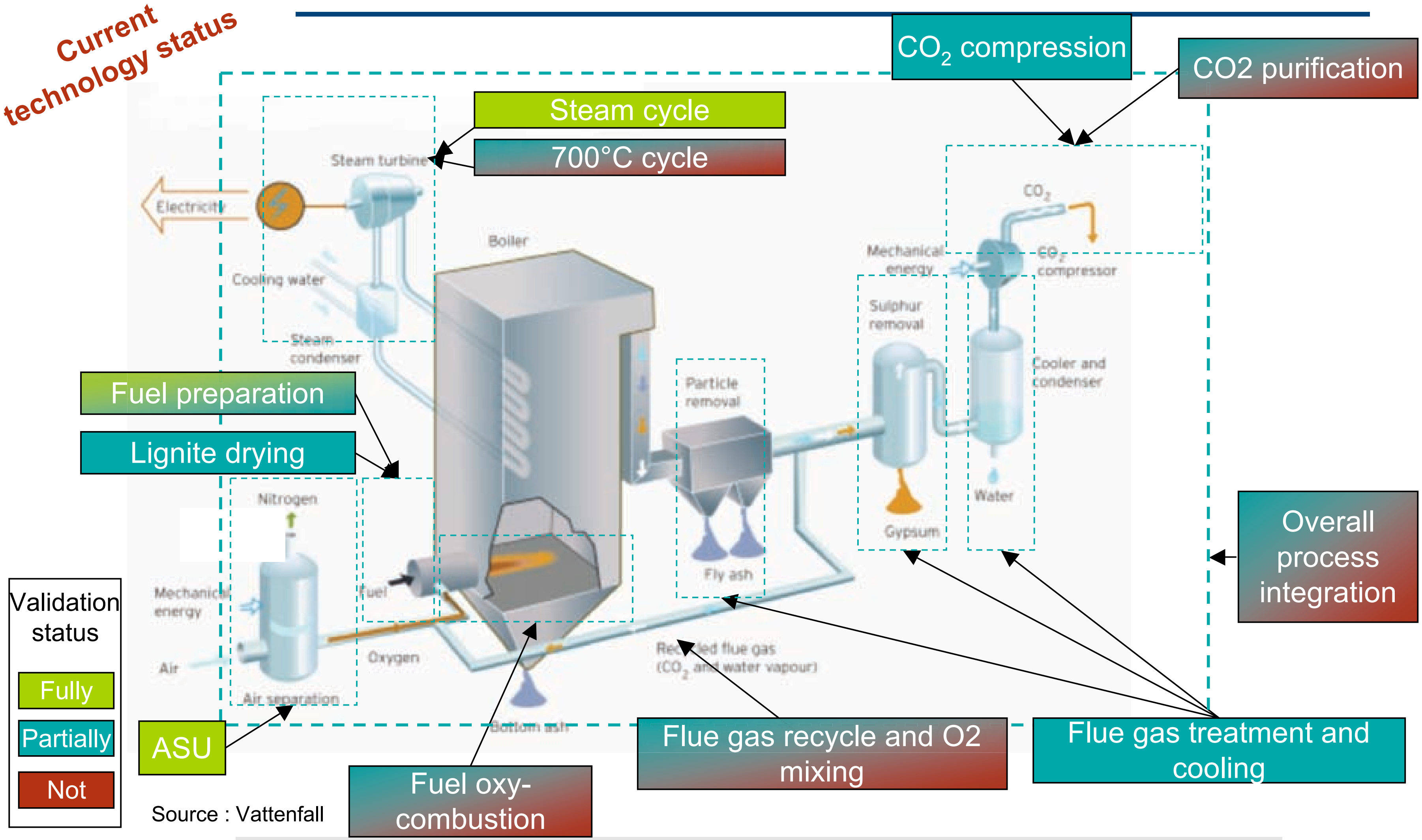
Validation status definition

Validation status	Principle
Not validated	Not tested / Less advanced than pilot scale
Partially validated	Ready for large demo project
Fully validated	Commercially available

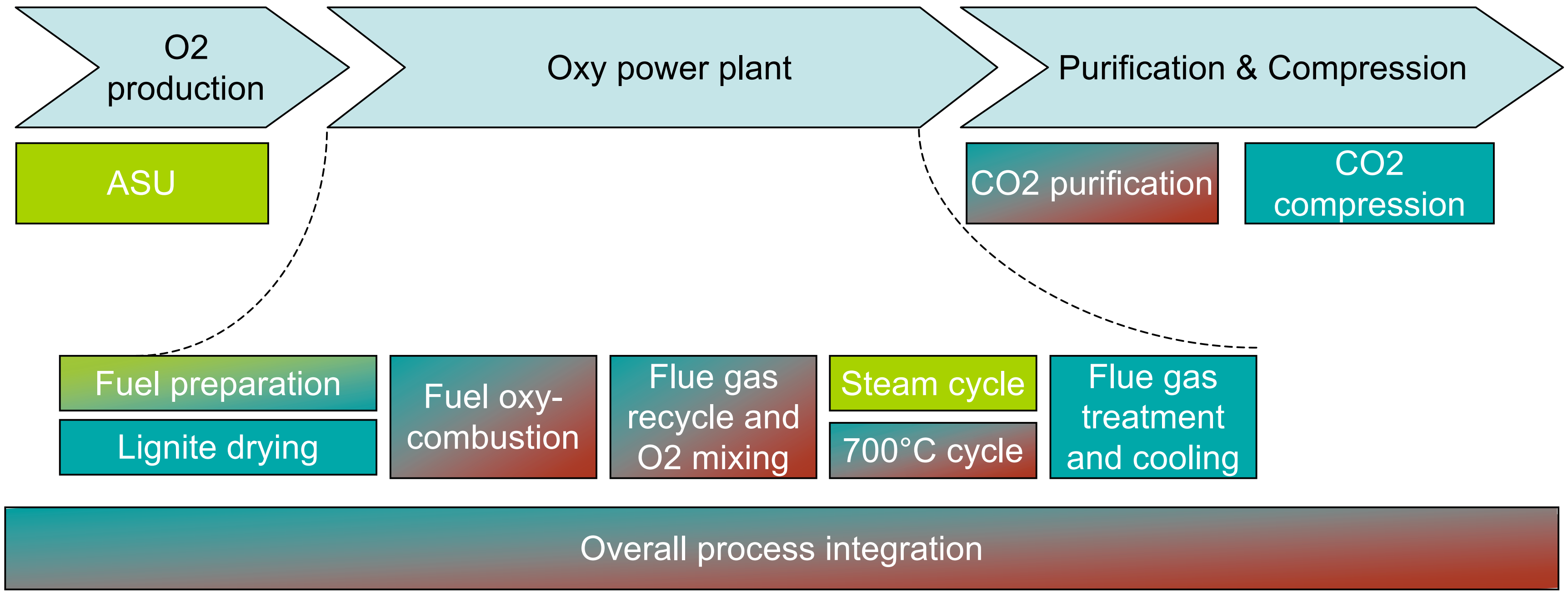
Oxyfuel technology blocks (boiler-based) – current validation status



Source : Vattenfall

Significant R&D and demonstration work required

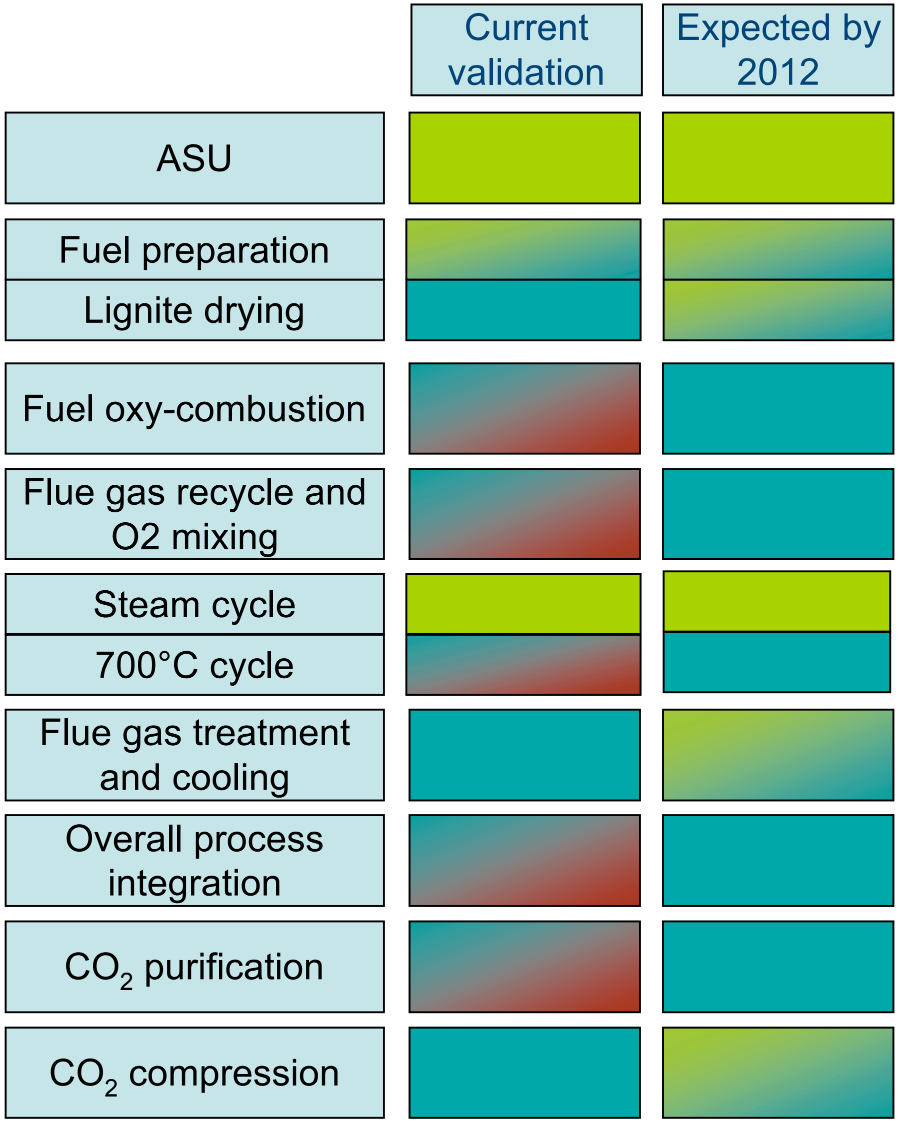
Oxyfuel technology blocks – current validation status



Significant R&D and demonstration work required

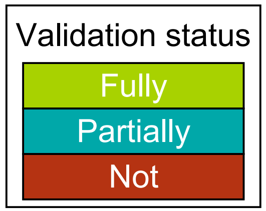
Validation status
Fully
Partially
Not

Oxyfuel technology blocks – expected performance improvement

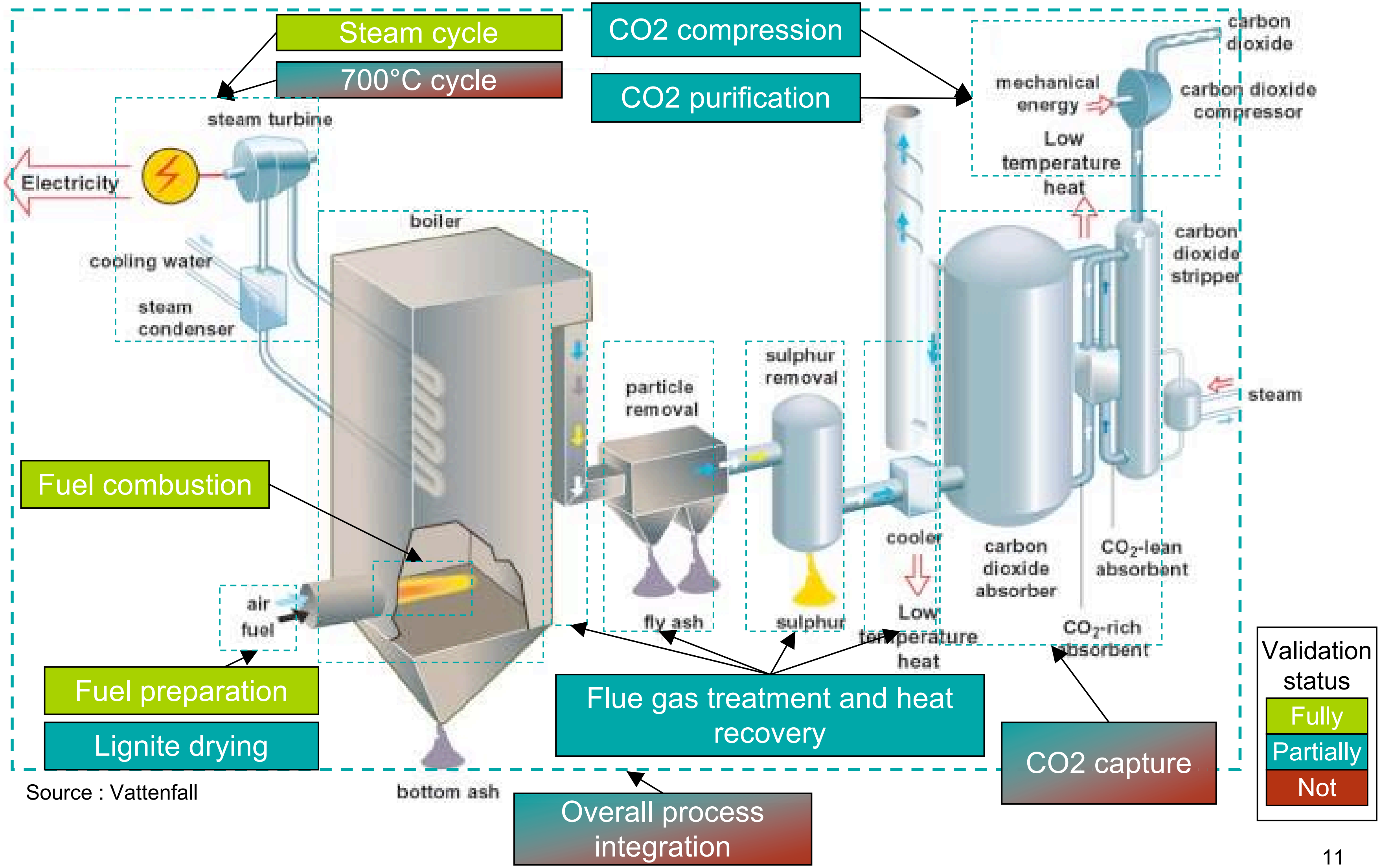


Major steps on lignite drying, oxy combustion and flue gas recycle and treatment

Advances to be done mainly on high rank coal and gas

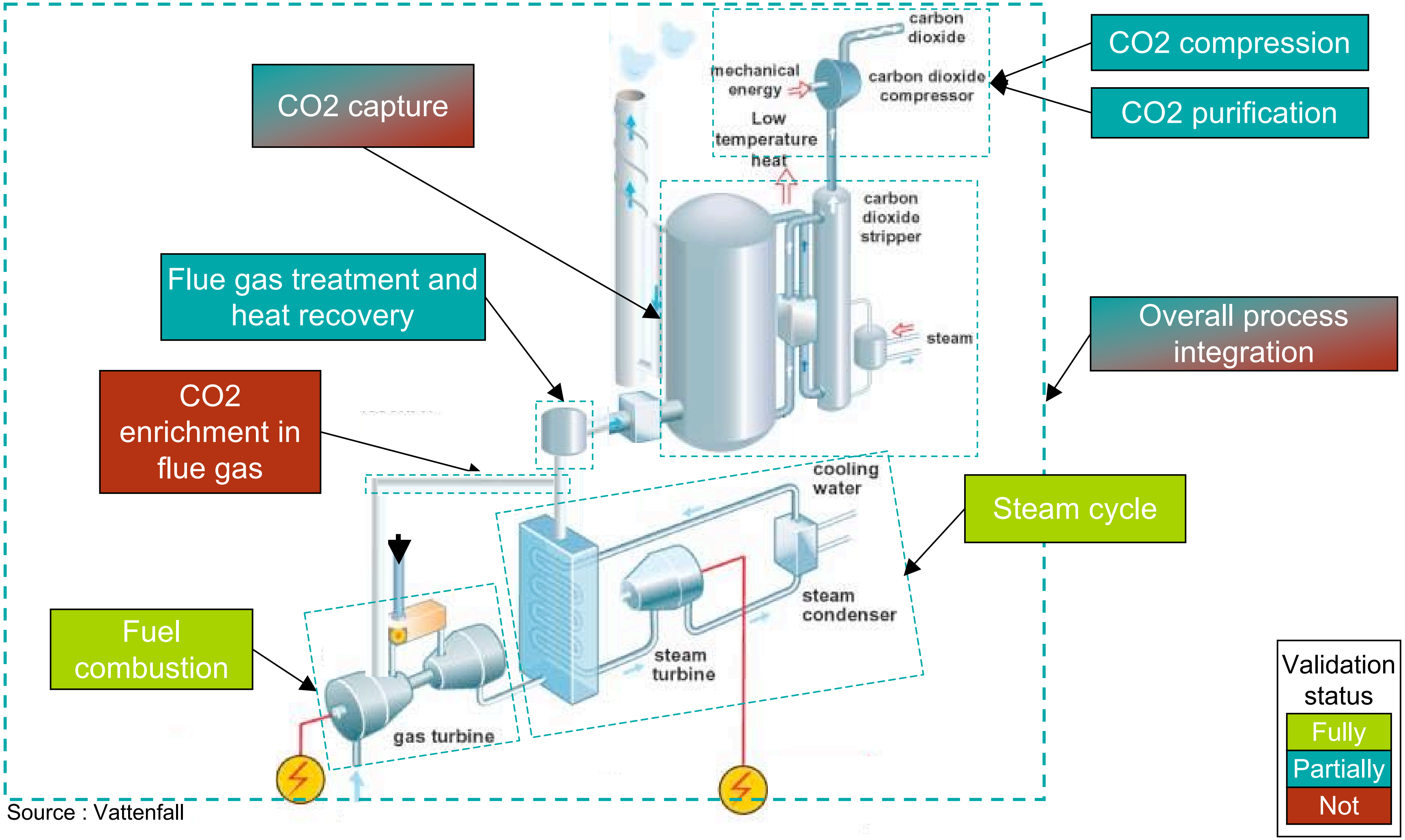


Post-combustion (boiler-based) – current validation status



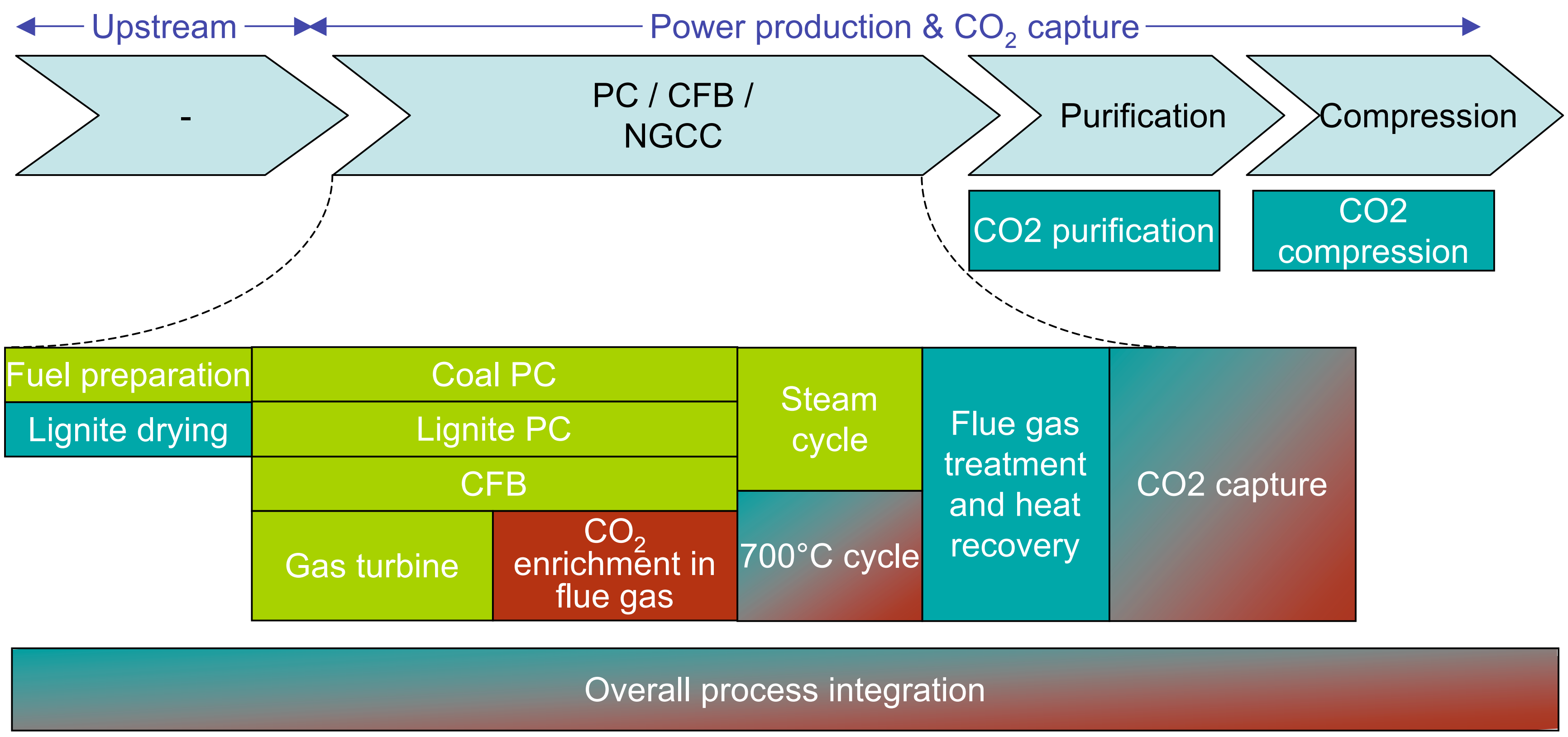
Source : Vattenfall

Post-combustion (GT-based) – current validation status



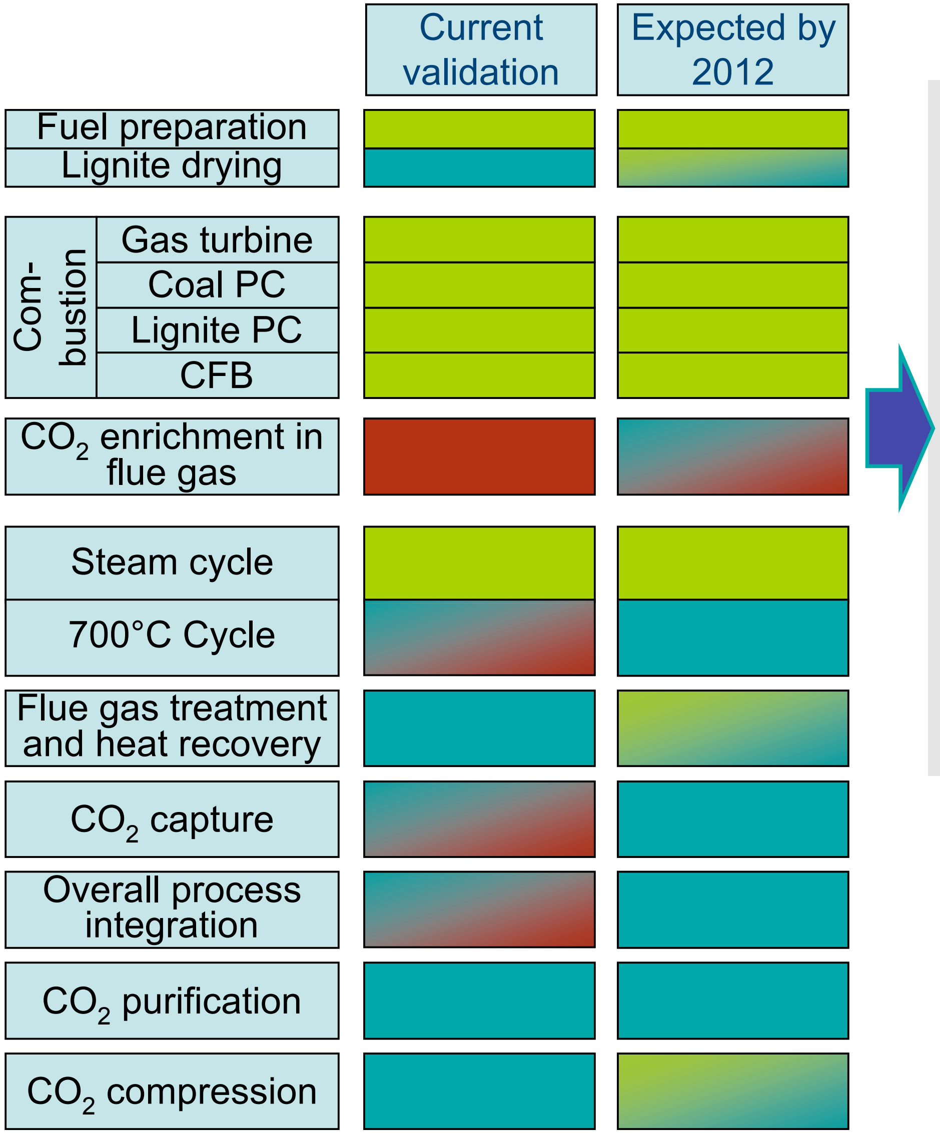
Source : Vattenfall

Post-combustion technology blocks – current validation status



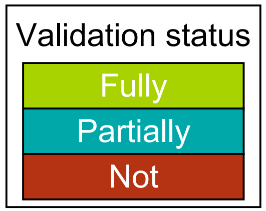
Capture blocks to be validated (Amines, Ammonia…)
Boiler-based process more advanced

Post-combustion technology blocks – expected performance improvement

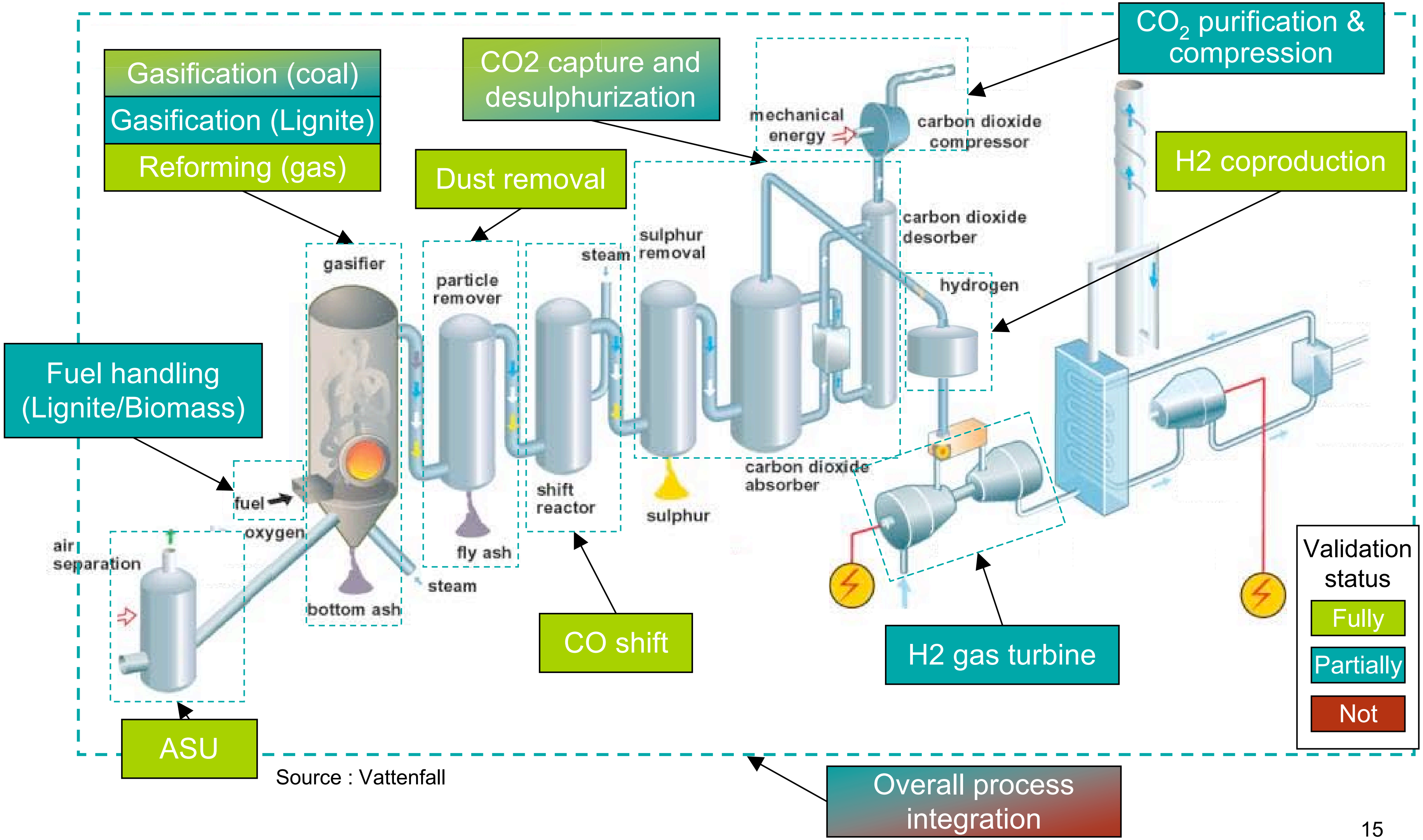


Work on power island technology blocks mainly on low rank fuels and steam cycle performance enhancement

Main focus to be put on validation of capture and process integration blocks

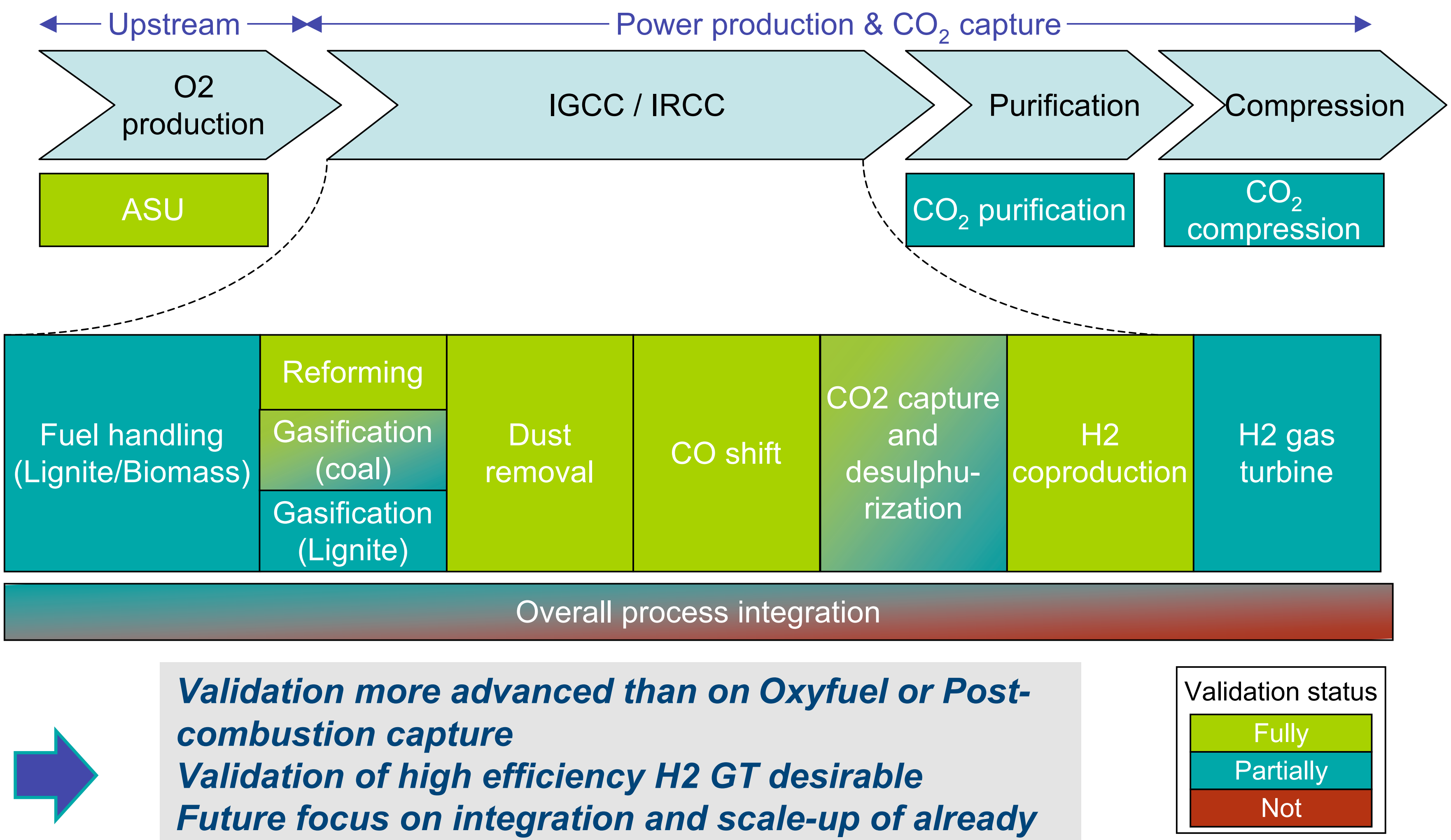


Pre-combustion technology blocks – current validation status



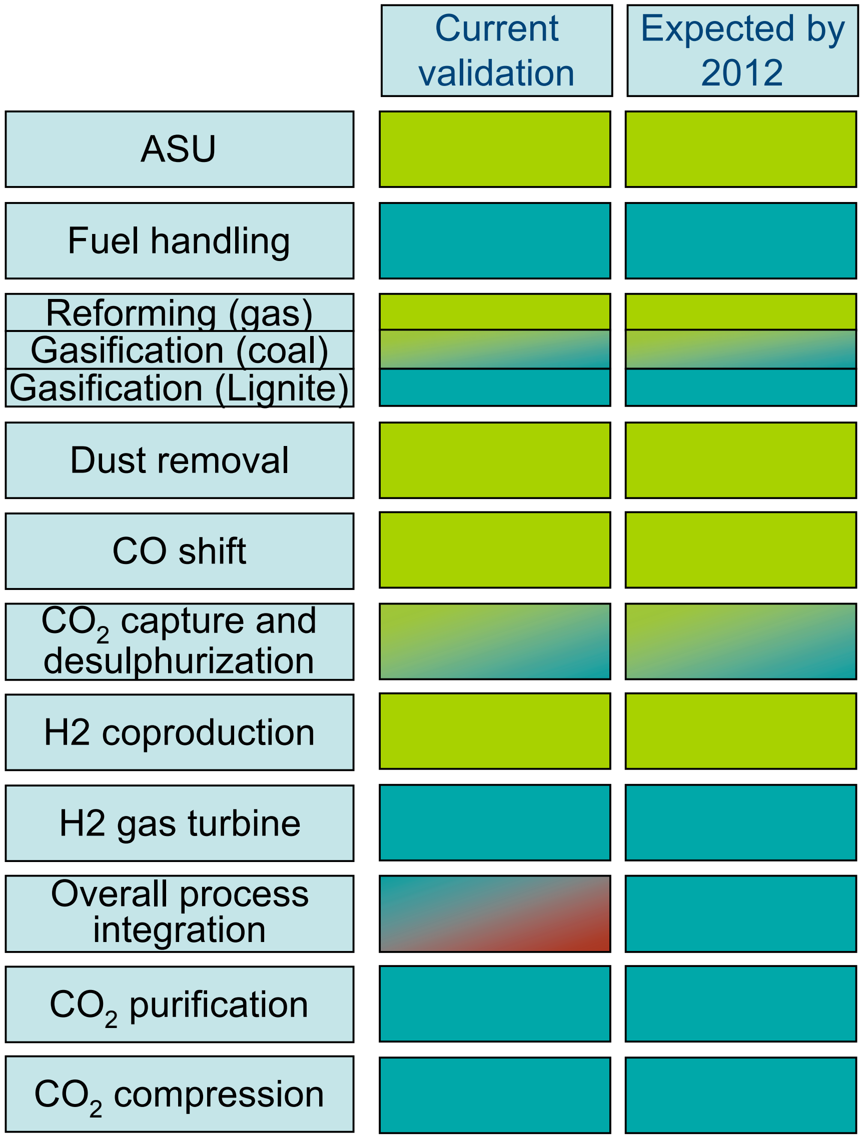
Source : Vattenfall

Pre-combustion technology blocks – current validation status



Validation more advanced than on Oxyfuel or Post-combustion capture
Validation of high efficiency H2 GT desirable
Future focus on integration and scale-up of already proven blocks

Pre-combustion technology blocks – expected performance improvement



Validation more advanced than on other technologies

- *Lignite/Biomass fuels only partially validated for the different technology blocks*

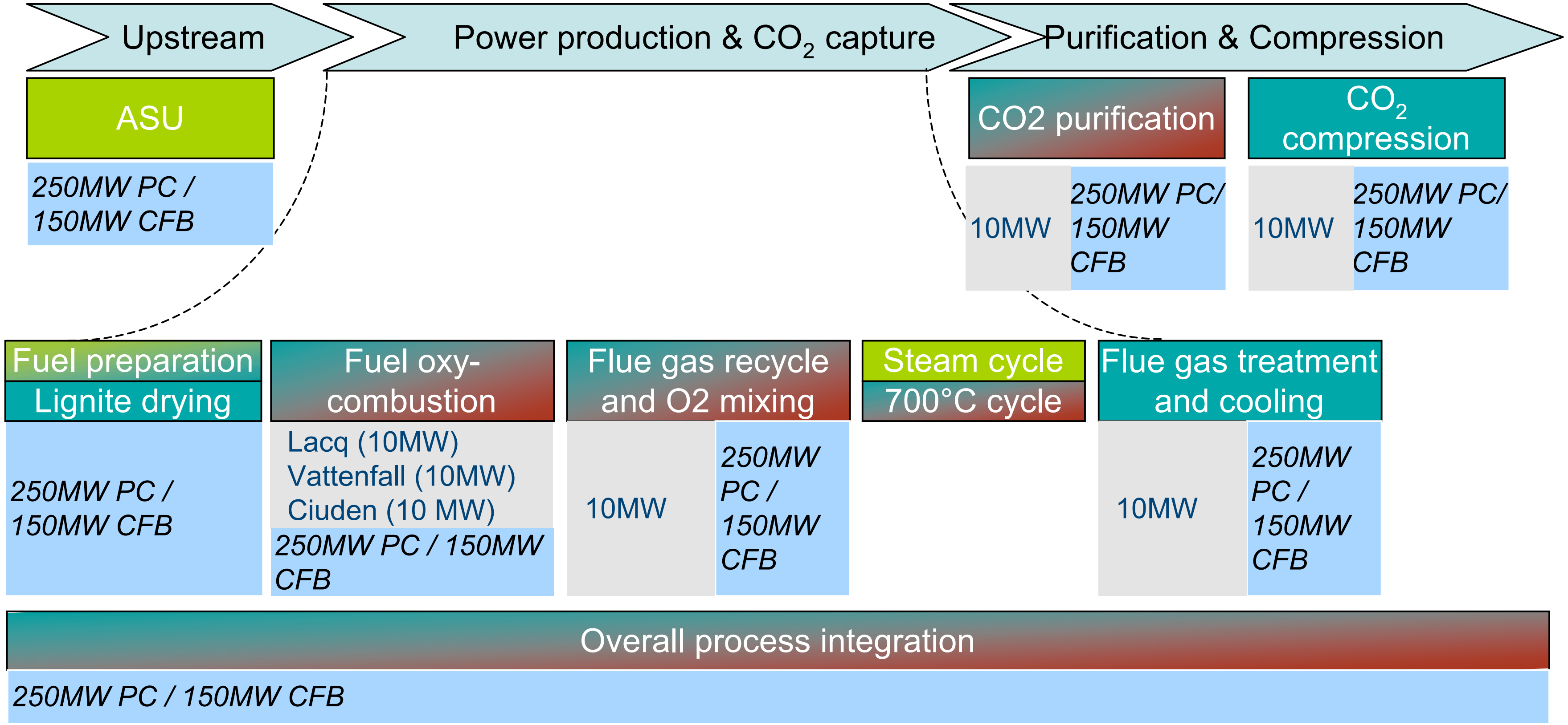
Limited validation expected by 2012

Focus to be put on process integration

Validation status

- Fully
- Partially
- Not

Current validation initiatives – Oxyfuel

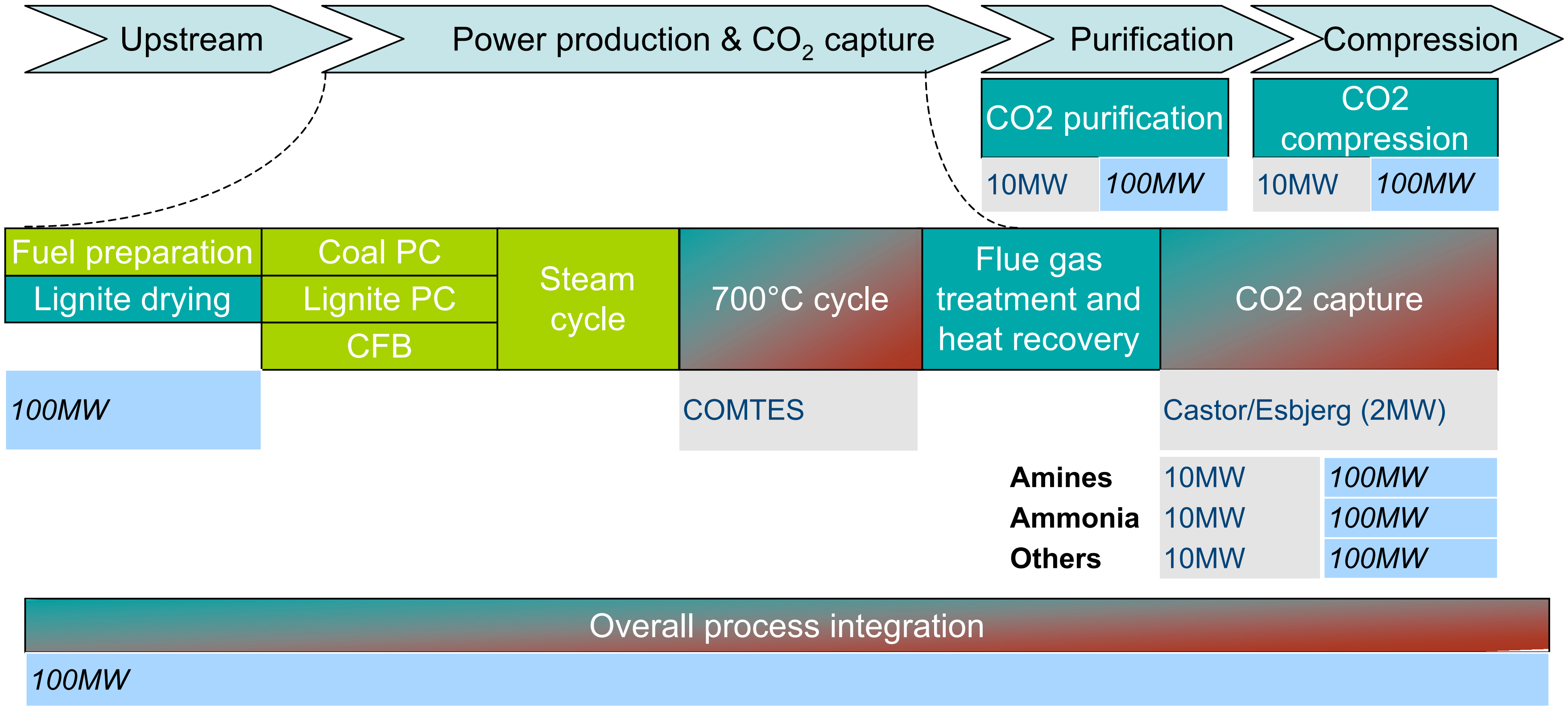


All capacities are expressed in MW Gross electrical

- ***A few validation initiatives operating or under construction.***
- ***Need for a set of large demos for ASU, boiler and components scale-up and integration***

Validation status	
Fully	Industry initiatives (existing or potential)
Partially	*Required large scale Demo projects*
Not	

Current validation initiatives – Post-combustion (boiler-based)



All capacities are expressed in MW Gross electrical

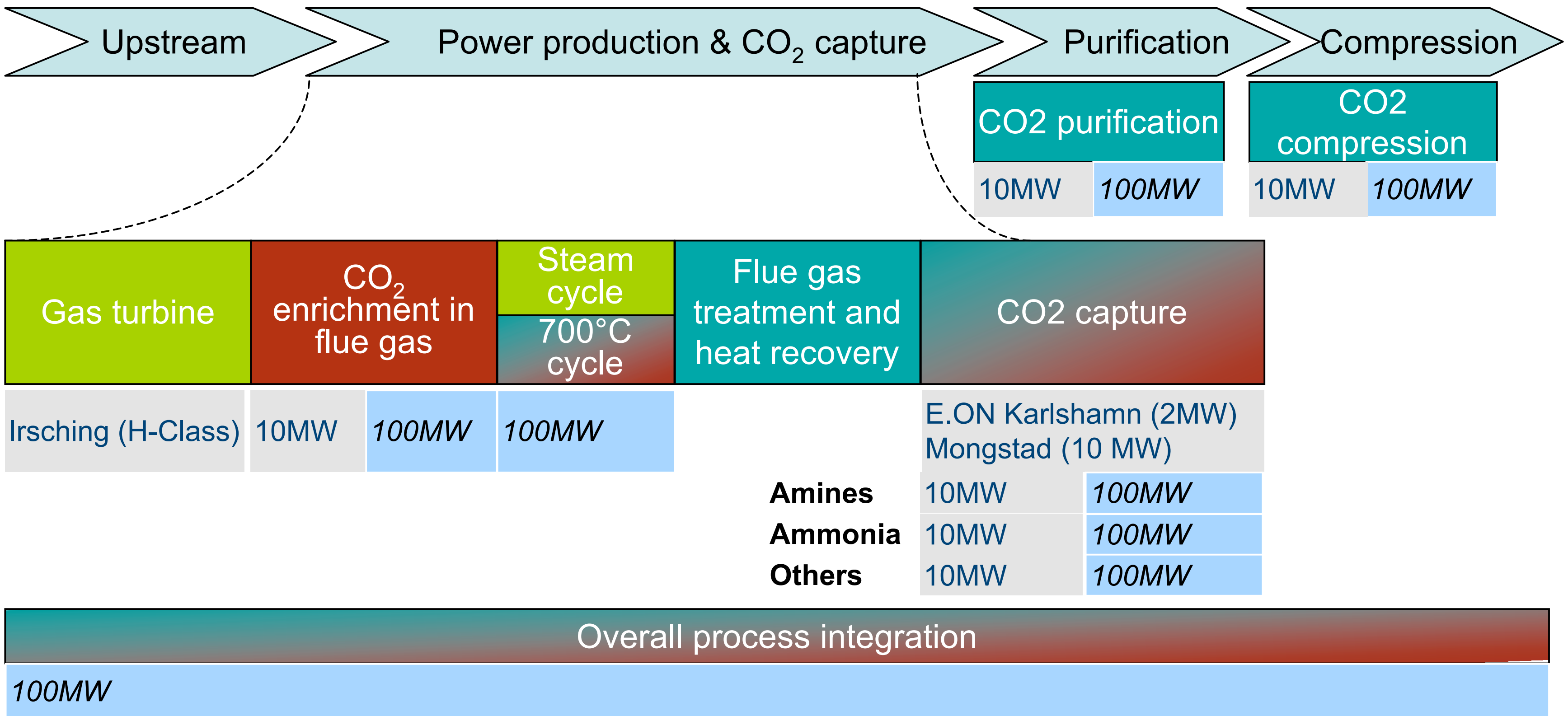
- ***A few validation initiatives operating or under design and construction.***
- ***Need for a set of large demos for capture scale-up and integration***

Validation status
- Fully
- Partially
- Not

Industry initiatives (existing or potential)

Required large scale Demo projects

Current validation initiatives – Post-combustion (GT-based)



All capacities are expressed in MW Gross electrical

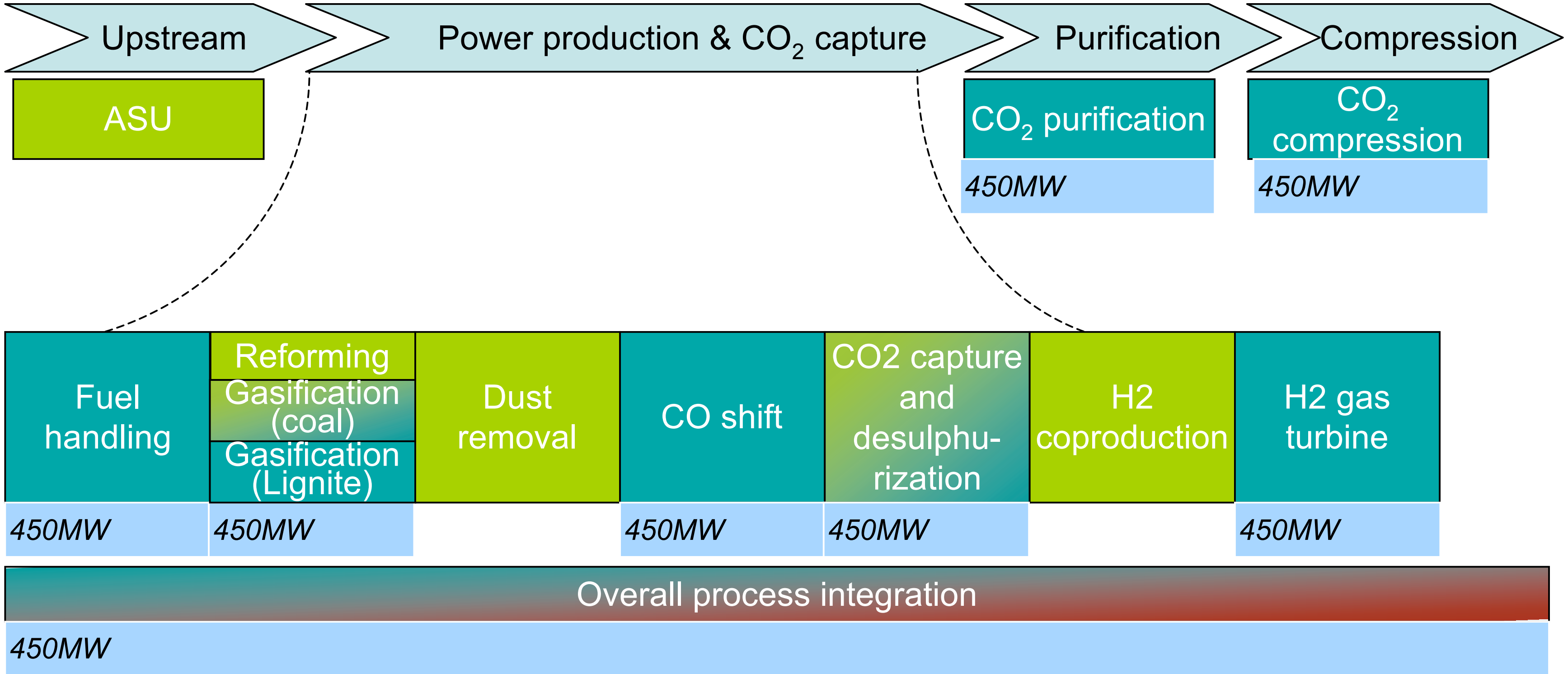
- ***A few validation initiatives operating or under construction.***
- ***Need for a set of large demos for capture scale-up and integration***

Validation status
- Fully
- Partially
- Not

Industry initiatives (existing or potential)

Required large scale Demo projects

Current validation initiatives – Pre-combustion



All capacities are expressed in MW Gross electrical
450MW is based on diffusion technology

- ***No further validation initiatives for the moment***
- ***Need for a set of demos to validate integration and components scale-up***

Validation status	
Fully	Industry initiatives (existing or potential)
Partially	*Required large scale Demo projects*
Not	

CO_2 capture – synthesis

- Difference in validation status within the different CO_2 capture technologies
  - Pre-combustion technology blocks more advanced than for Post-combustion and Oxyfuel
  - Overall integration is the less advanced technology block
- Additional work needed on non-capture technology blocks to enhance plant performances and ease integration of CO_2 capture systems
- A number of large demonstration projects are under evaluation in the industry

Need for a large number of demo projects to validate technology blocks and integration

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Efficiency improvement

	Target
Steam cycle	Increase steam parameters (350 bars, 700/720°C) New Ni-based alloys to be tested

	Performance increase	Validation initiatives
Turbine	New material	COMTES Cooretec
Boiler	New material testing and manufacturing	COMTES MARCKO
Plant	New material identification and testing	COMTES AD700

Efficiency improvement through steam parameter increase should ease CO_2 capture validation in Post and Oxy

Validation status
Fully
Partially
Not

Demo projects

Efficiency gains potential

Technology blocks	Potential efficiency gains compared to current state-of-the-art* (Additional % points)	Impact on CO2 emissions and/or CCS efficiency	
ASU	+ 0,5 to 2 points	IGCC & Oxy	Medium
Gas turbine	+ 0,5 to 2 points	Low / Medium	
Boiler Steam Cycle	+ 2 to 4 points	Strong	
Fuel preparation Lignite/Biomass	+ 1 to 4 points	IGCC & Oxy	Strong
		Post	Medium
Plant integration	+ 1 to 4 points	Strong	

Focus to be on Boiler/Steam cycle and Plant integration

Notes: *Combining several potential sources of gains does not necessarily lead to the addition of % points
4pts of efficiency is equivalent to 10% gain in overall performance

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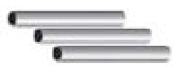
CO_2 capture, transport and storage value chain

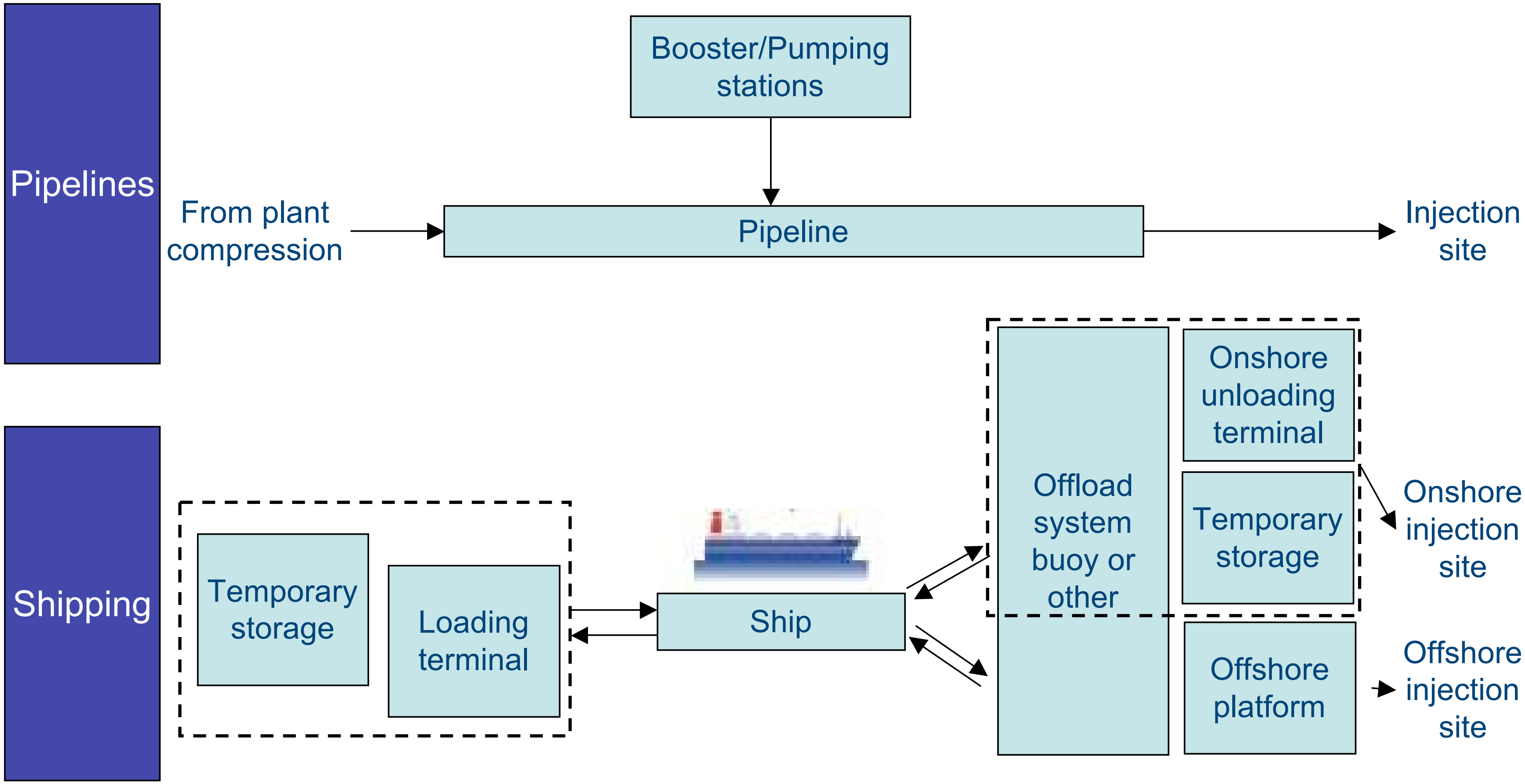
Power plant → **Transport infrastructure** → Storage infrastructure

Pipelines	*Ship*	Rail/truck tankers
• Onshore pipeline (already operational) • Offshore pipeline (already operational)	• Comparable to ship transportation of liquefied petroleum gas (LPG) • Already operational	• Already operational (CO_2 for beverage)



Preferred options	*Difficult option for large-scale operation*	*Not considered as attractive option for large-scale transport*

Transport processes explanation



Pipeline transport technology blocks – current validation status

Pipelines

Booster/Pumping stations

From plant compression

Pipeline

Injection site

Cortez (US)
Sheep Mountain (US)
Val Verde (US)
Canyon Reefs Carriers (US)
Bravo (US)
Weyburn (US/Canada)

Bati Raman (Turkey)
Snohvit (Norway)
Croatia EOR
South Arne (Denmark)
Lacq (France)

Integration with CO_2 capture power plant and injection site

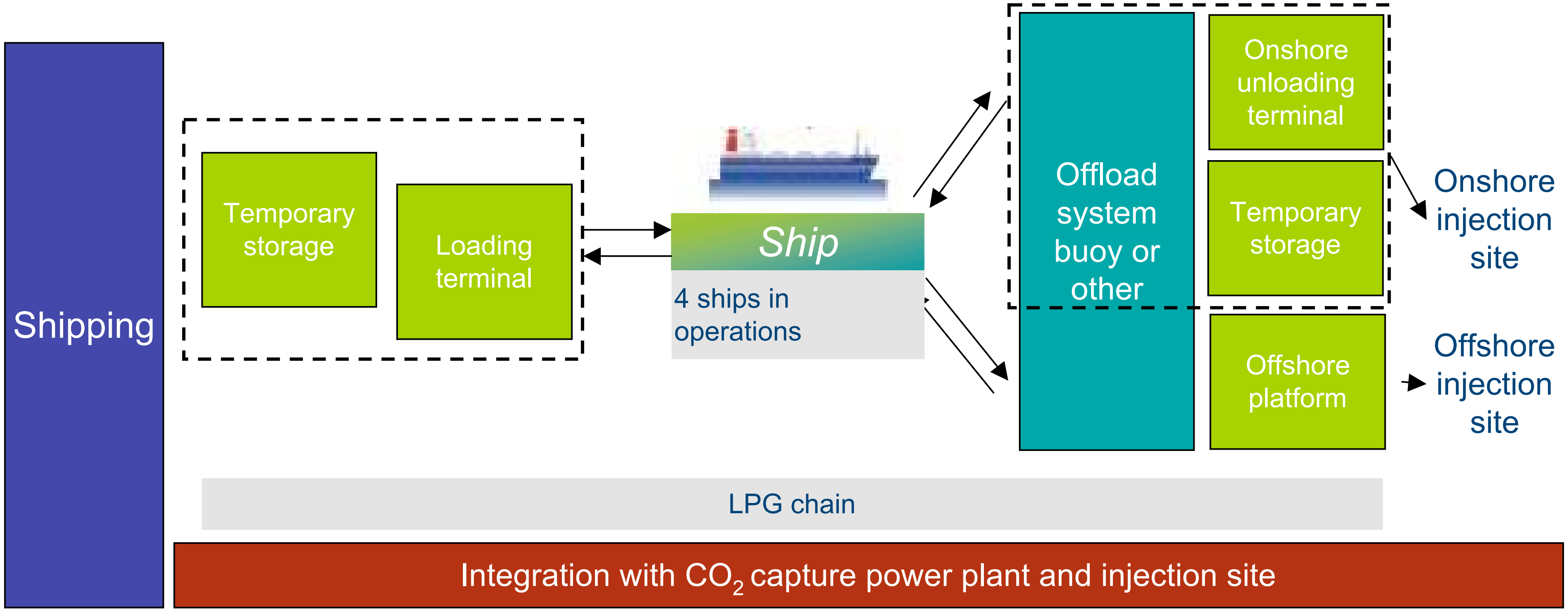
- *Mature technology*
- *Only work on integration with large power plant required – all else proved*

Validation status

- Fully
- Partially
- Not

Commercial/Demo projects

Ship transport technology blocks – current validation status



- *Less mature technology, although close to LPG*
- *Strong work on integration with capture and storage required*
- *Ship flow vs. CO_2 generated from large plant*

Commercial/Demo projects

Validation status
- Fully
- Partially
- Not

Transport processes work flow – current validation status

Pipelines

Design → Construction → Operation

Design basis
- Network design
- Safety review

Conceptual design
- Mechanical design
- Stability design
- Protection against corrosion
- Trenching

Monitoring
- External monitoring
- Instrumentation and control

Maintenance
- Daily maintenance
- Scheduled inspecting and repairing
- Cleaning

Shipping

Ships

Design → Construction → Operation

- Design/construction close to LPG carrier
- 4 small CO_2 carrier already in operation
- CO_2 carriers fleet management not experienced

Terminals

Design → Construction → Operation

- Design/construction/operation close to LPG terminals

- *Workflow of transport options well-advanced*
- *Main work will be on network definition*

Validation status
Fully
Partially
Not

CO_2 transport – synthesis

- Technology blocks more advanced than capture
  - Pipeline transport is commercially mature
  - Shipping transport already operating but at small scale
- Main challenge will be network definition and transport infrastructure organisation
  - Pipeline network (backbone) in densely populated areas
  - Ship fleet management/integration with capture and storage
- No validation initiative on ship transport

Need for validation initiatives in shipping and CO_2 pipeline network definition

CO_2 capture, transport and storage value chain

Power plant → Transport infrastructure → Storage infrastructure

Depleted Oil and Gas fields	Deep saline aquifers	Enhanced Coal Bed Methane	Enhanced Oil or Gas Recovery (EOR/EGR)
• Onshore or offshore depleted oil and/or gas field	• Permeable sedimentary rock formation saturated with water	• Coal Bed Methane extraction through injection of CO_2	• Already operational (several large projects, US, Brazil, Turkey…)
Options in development		*In development, limited potential*	*Mature option*

CO_2 storage process explanation
Depleted fields/Deep saline aquifers

Power plant → Transport infrastructure → Storage infrastructure

Storage infrastructure: Basin wide screening → Site maturation and testing → Baseline monitoring and verification → Operatio n → Site closure

Outcome

Basin wide screening

- Ranked list of potential storage sites
- Identification of data and knowledge gaps

Site maturation and testing

- Identification and test of one or more viable storage sites

Baseline monitoring and verification

- Definition monitoring and verification process
- Barrier modelling

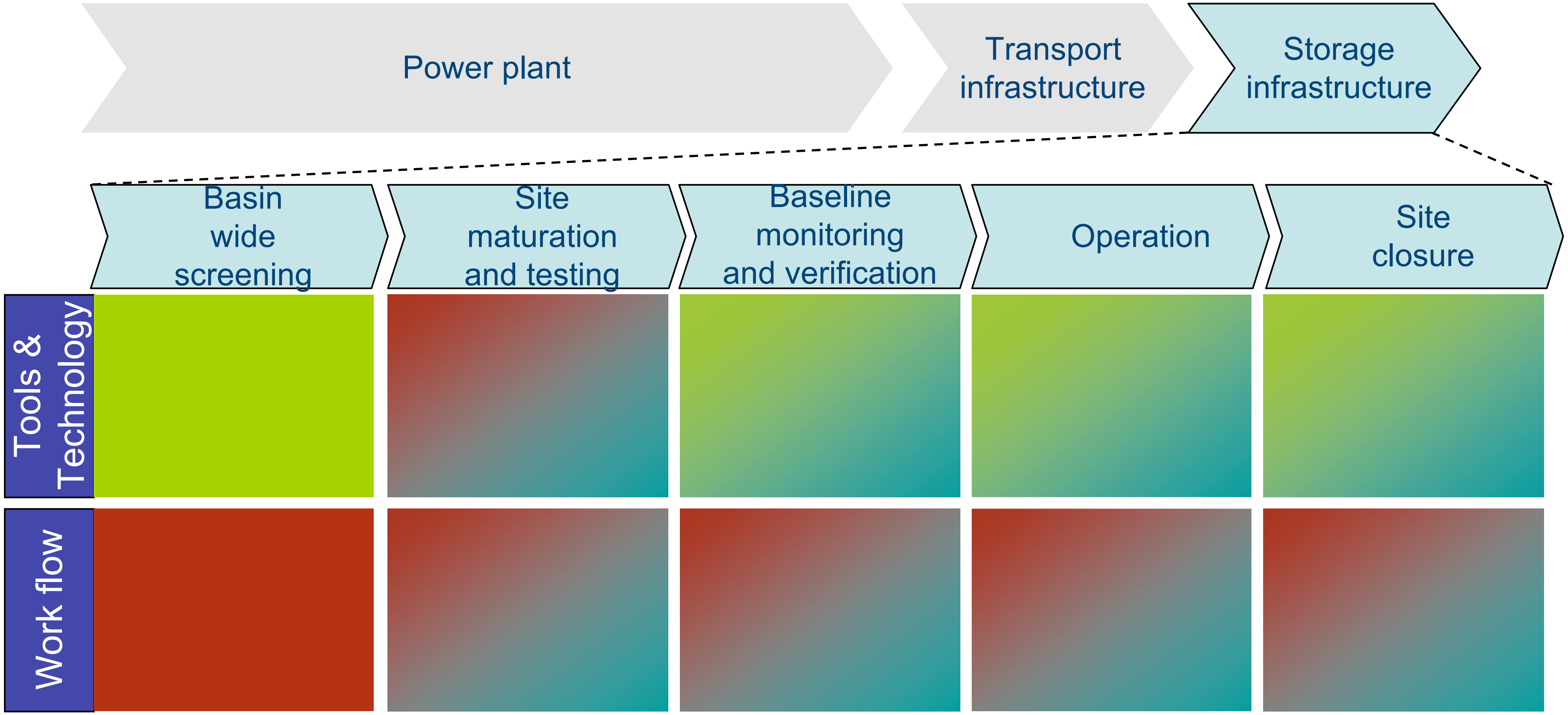
Operatio n

- Design and location of injection wells
- Drilling and completion wells
- CO_2 injection
- Well integrity assurance

Site closure

- Closing down injection and facilities leaving only monitoring equipment in place
- Post-injection monitoring

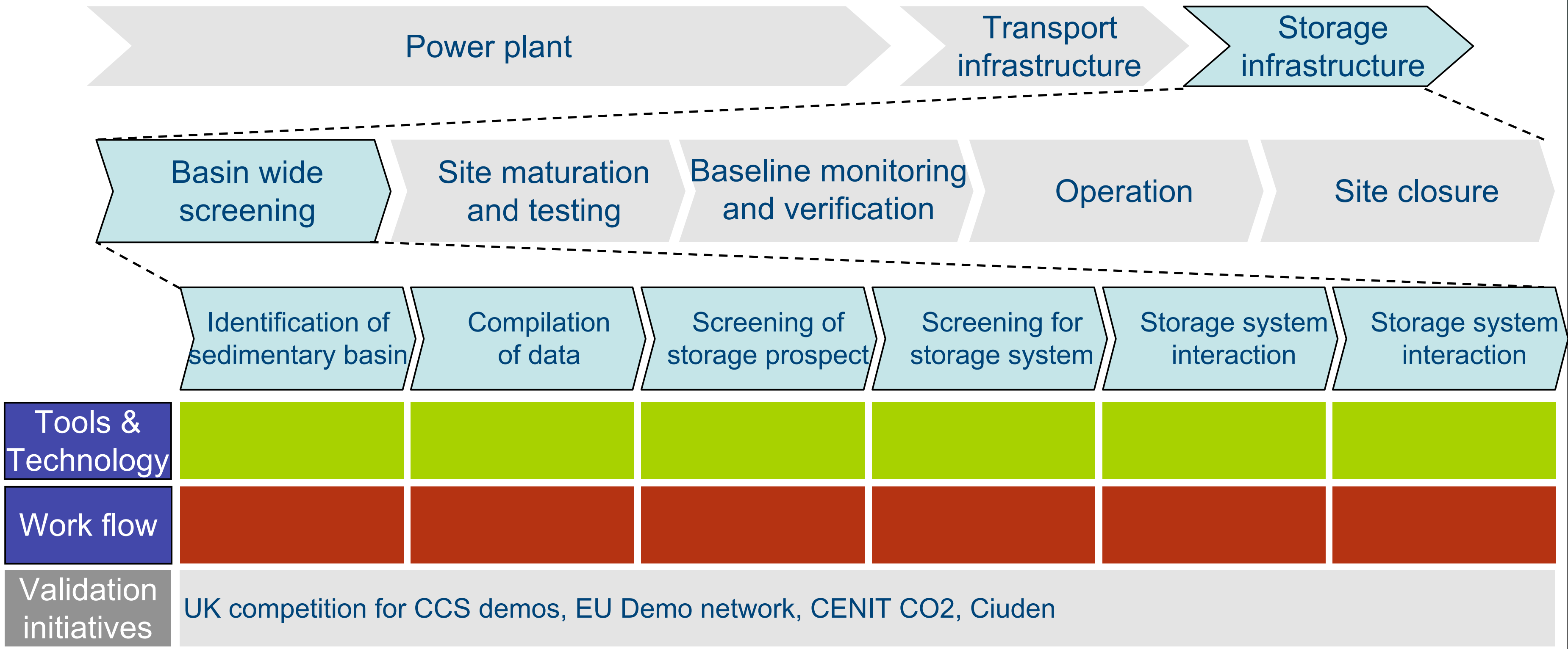
CO_2 storage overall validation status
Depleted fields/Deep saline aquifers



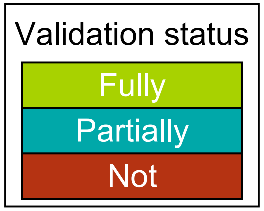
- *Tools and technology almost ready*
- *Work on workflow definition required*

Validation status
- Fully
- Partially
- Not

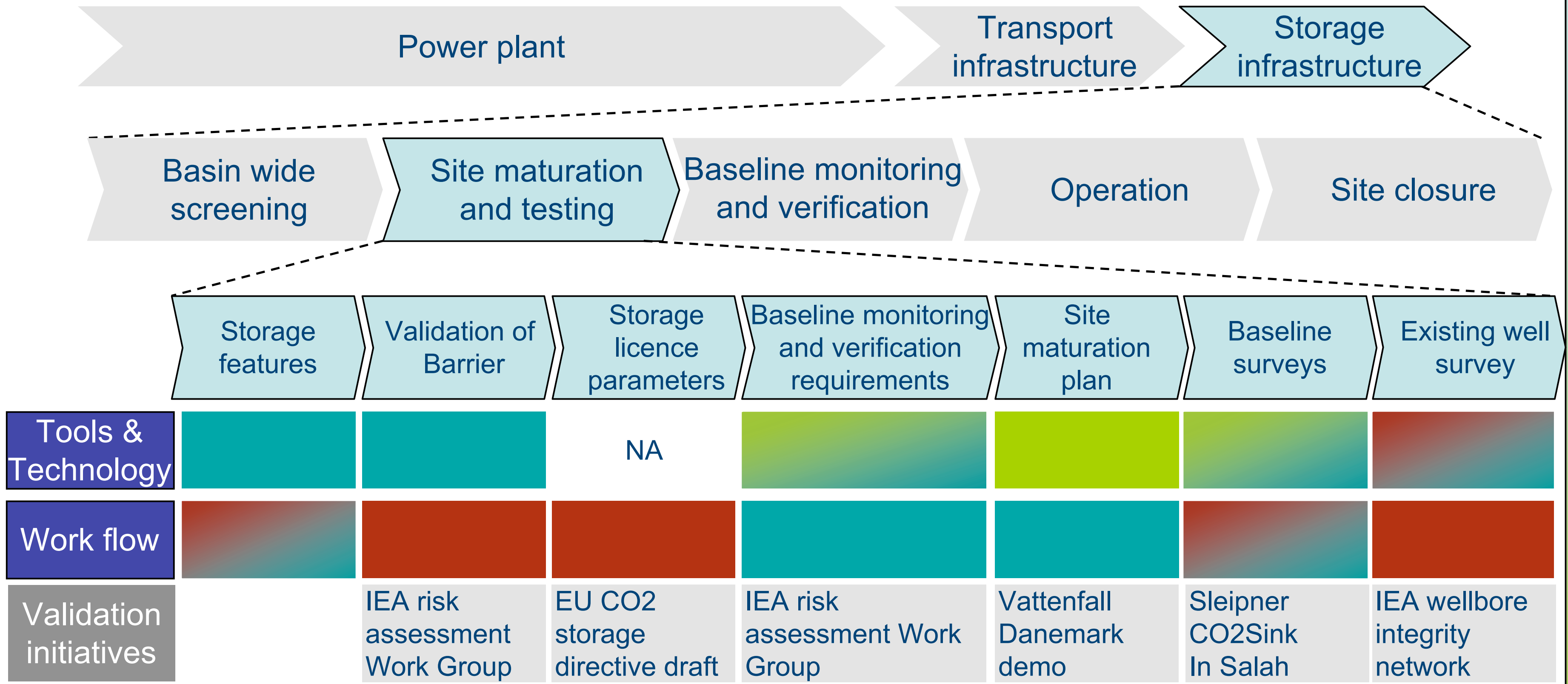
CO_2 storage detailed validation status Depleted fields/Deep saline aquifers (1/5)



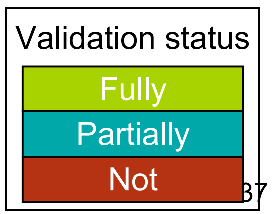
- *Tools and technology ready*
- *Work on workflow definition required*



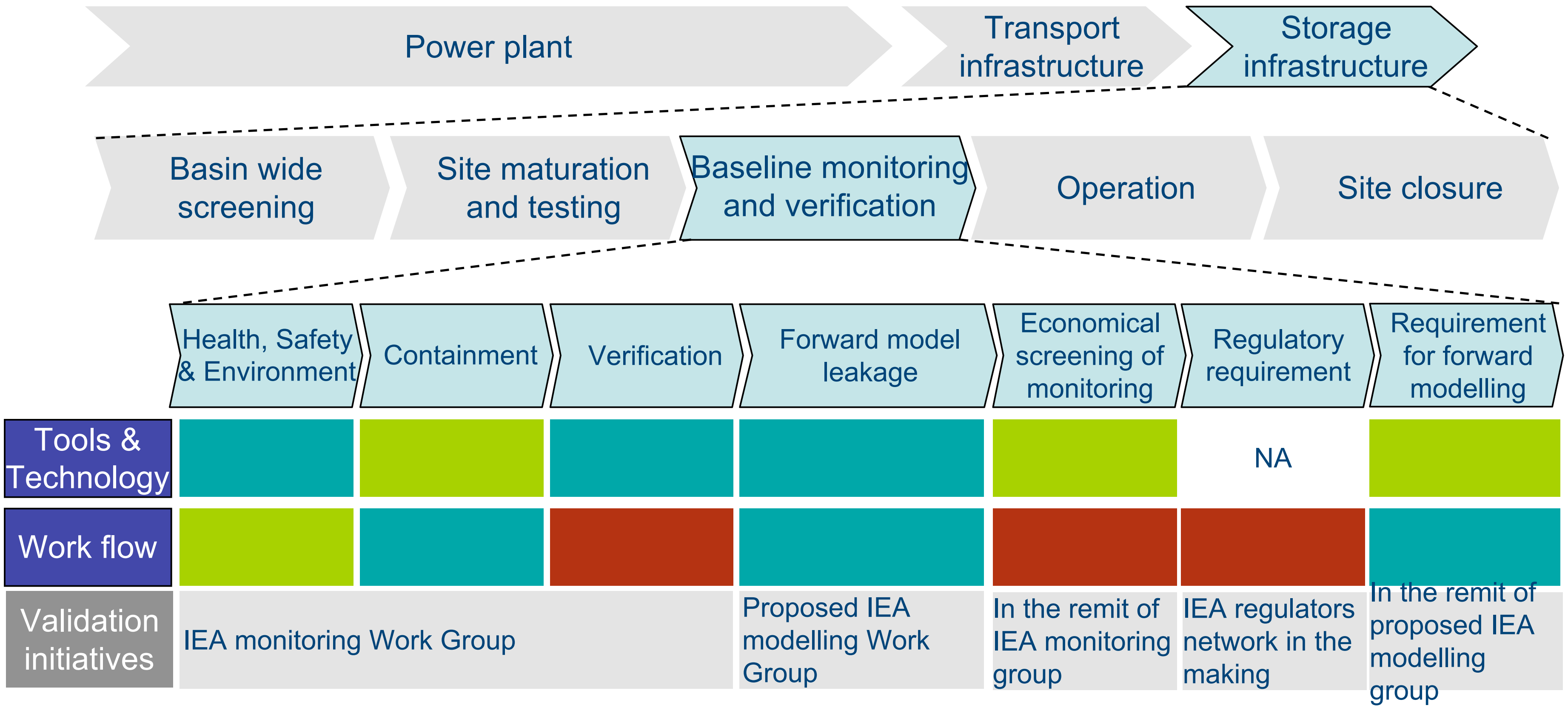
CO_2 storage detailed validation status Depleted fields/Deep saline aquifers (2/5)



- *Tools almost ready except for existing wells*
- *Strong work on workflow required for almost all blocks except for monitoring and verification*



CO_2 storage detailed validation status Depleted fields/Deep saline aquifers (3/5)

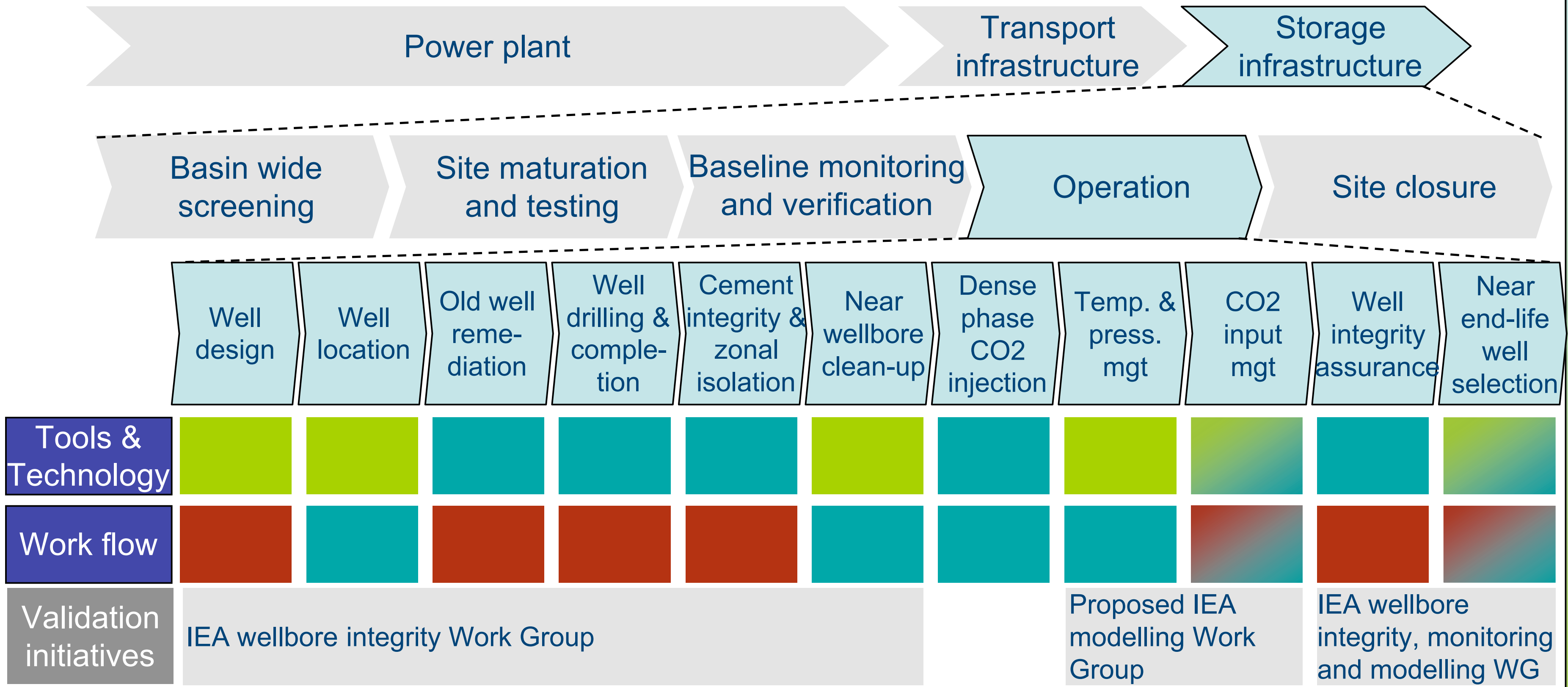


- *Strong work on workflow required for containment, economical screening of monitoring and regulatory requirement*
- *Validation initiatives more on theoretical definition*

Validation status

- Fully
- Partially
- Not

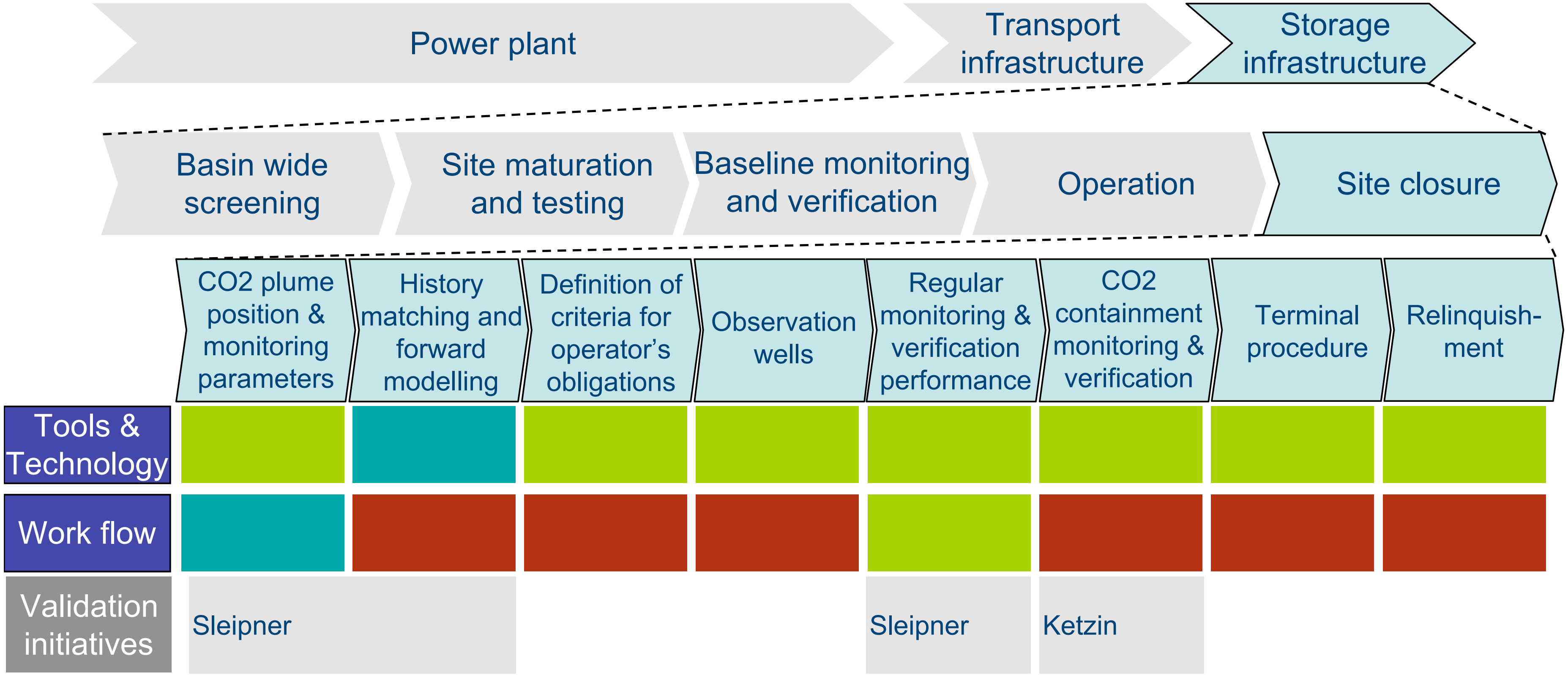
CO_2 storage detailed validation status Depleted fields/Deep saline aquifers (4/5)



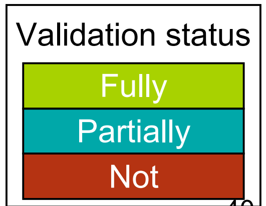
- *Strong work several workflow*
- *Validation initiatives more on workflow definition, to be adapted on real projects*

Validation status
- Fully
- Partially
- Not

CO_2 storage detailed validation status Depleted fields/Deep saline aquifers (5/5)



- *Strong work on workflow required*
- *More limited validation initiatives*

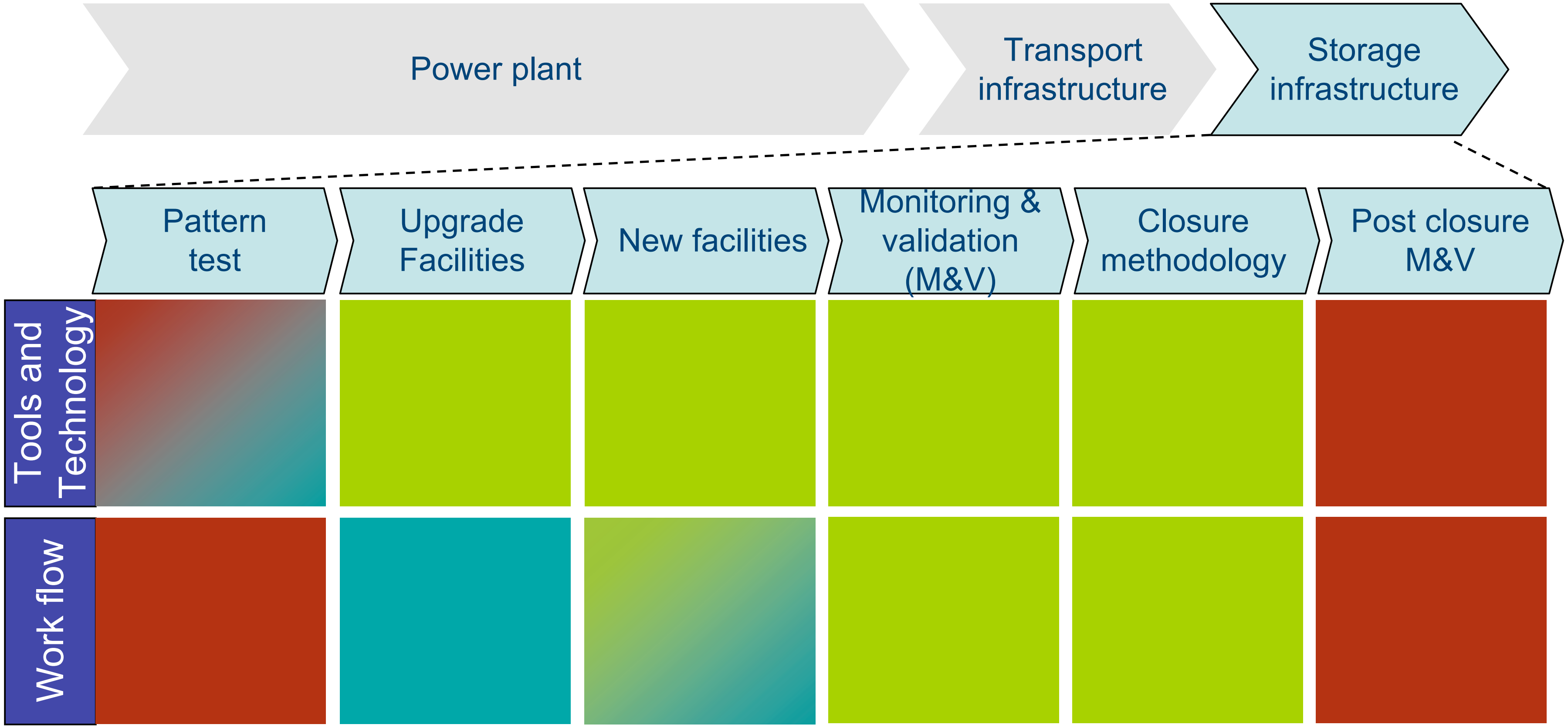


CO_2 storage process explanation ECBM

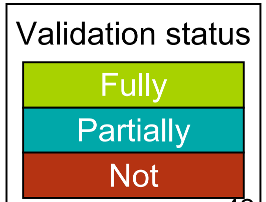
Power plant → Transport infrastructure → Storage infrastructure

Outcome	Pattern test	Upgrade Facilities	New facilities	Monitoring & validation (M&V)	Closure methodology	Post closure M&V
	• Evaluation of ECBM production • Proof of long-term injectivity of CO_2 • Assessment of CO_2 effect on ECBM	• Well site space identification • Prevention of corrosion	• Drilling and completion of wells • Integration of compression site and well site designs	• Detection of leakage both concentra-tion and flux • Detection of CO_2 / CH4 presence in water	• Closing down injection and facilities leaving only monitoring equipment in place	• Post-injection monitoring

CO_2 storage overall validation status ECBM



- *Tools and technology almost ready*
- *Work on workflow definition required*



CO_2 storage – synthesis

- Technology and tools are well advanced
  - Very few are not validated at all
  - Focus is more on adaptation and capability enhancement
- Main challenge will be work flow definition
  - Safe process definition
  - Adaptation of standard to CCS
  - Monitoring, verification requirement and operator's obligations definition
- Majority of validation initiatives are not backed by practical demo projects

Need for basin wide screening and practical validation projects

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CO_2 capture, transport and storage demo project requirements

Coverage of validation gaps by existing validation initiatives

	Power production & CO_2 capture	Purification & compression	Transport	Storage
Oxy	Very partial	None	Very partial on pipelines None on shipping	Workflow development Very partial in terms of projects
Pre	None			
Post	Very partial	None		
Demo project requirements	13-15 projects		1-2 projects per transport options	5-6 projects with priority on saline acquifer and DOGF

10-12 demo projects, potentially combining capture, transport and storage as a means of addressing 80% of technological validation gaps

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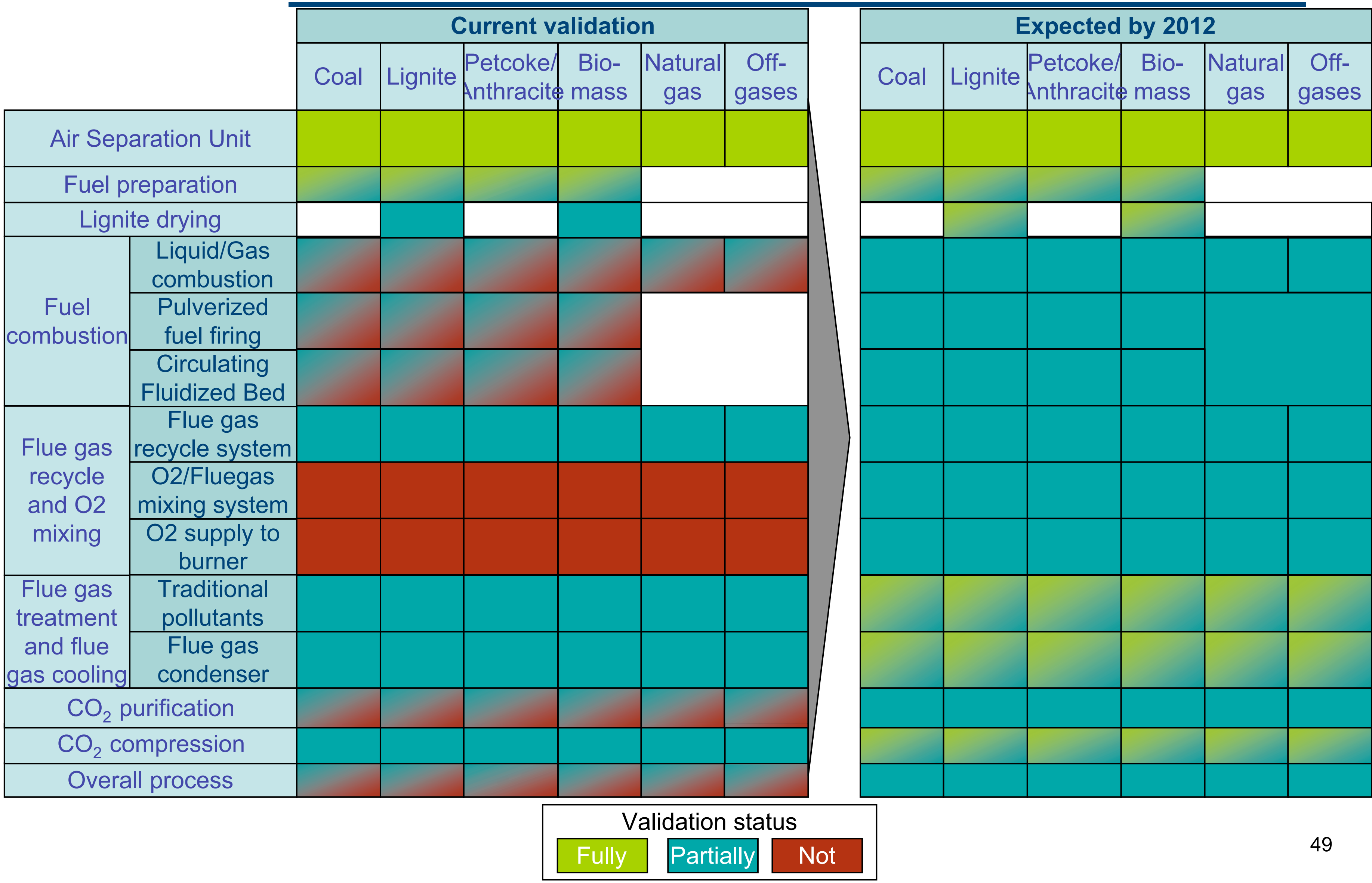
CO_2 capture, transport and storage value chain

		Combustion reaction	Principle
Post-combustion	Coal	$C + Air \Rightarrow CO_2$	Exhaust gas CO_2 cleaning
	Gas	$CH4 + Air \Rightarrow CO_2 + H2O$	
Pre-combustion	Coal	$C + O2 \Rightarrow CO$ $CO + H2O \Rightarrow CO_2 + H2$	C-free syngas burning
	Gas	$CH4 + H2O \Rightarrow CO_2 + H2$	
Oxy-firing	Coal	$C + O2 \Rightarrow CO_2$	High concentration CO_2 stream production
	Gas	$CH4 + O2 \Rightarrow CO_2 + H2O$	

Not selected CO_2 capture technologies

	CO2 capture technologies	Rational for exclusion
Oxy-firing	Natural gas-fired boiler	Very limited market
	Oxy GT	Not mature enough, require additional R&D and pilot testing to qualify for large-scale demonstration by 2012
	Chemical looping	
	High pressure oxy reactor	
Post-combustion	Membranes	
	Anti-sublimation	
	Enzymes	
	Algae	

Oxyfuel – detailed expected evolution of validation status



Oxyfuel – capacity and performance (1/3)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
ASU (for PC)	Cryogenic train	Integrated multi-train	O_2 flow (t/d)	4,300	7,000	3,500
			Power consumption (kWh/t)	250	>220	200
			Power consumption O_2 compression (kWh/t)	50	50	10-15
			Pressure out (Bar abs)	5	5	1.3
			Temperature out (°C)	Ambient	Ambient	Ambient
			Gross PG level (MWe)	One train	One train	250MWe
	Membranes	Membranes assumed not available in Flagship demo timeframe				
Fuel preparation		Drying for low grade fuels	Dryer throughput (t/h)	80	200	n x 200
Fuel oxy-combustion	Liquid/Gas combustion	With Steam w/o flue gas recycle	Gross PG level (MW)	5MWe	70MWe	250MWe
	Pulverized fuel firing	Including mill, commercial size burners (>40MWth), O_2 mixing/ flue gas recycle		0.5-1MWth	30MWth	250MWe
	Circulating Fluidized Bed	With flue gas recycle and O_2 mixing		0.1-1MWth	10sMWe	150MWe

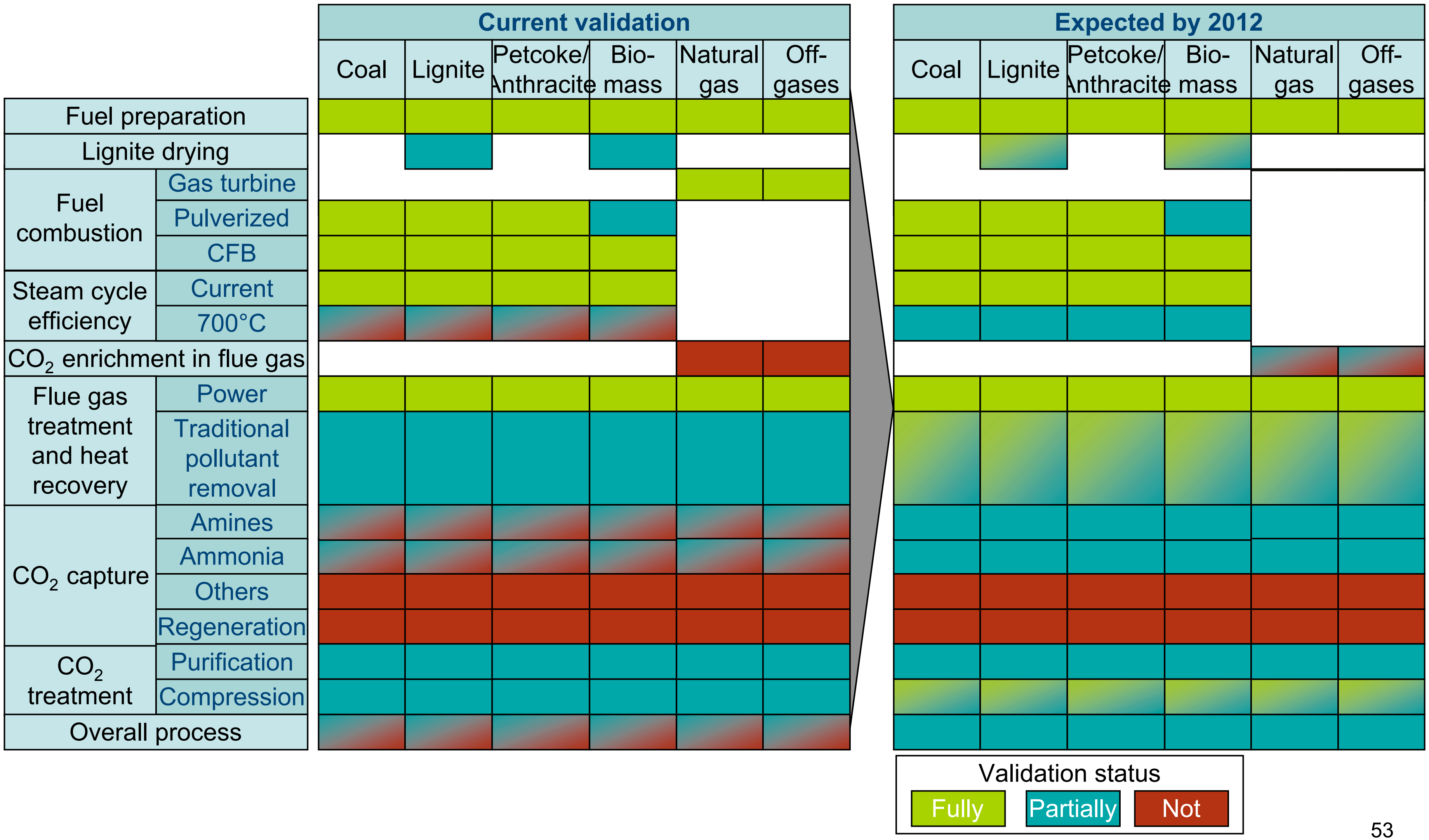
Oxyfuel – capacity and performance (2/3)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Steam cycle		Increase steam cycle efficiency	Scoring factor (% LHV, without CCS)	43	46	Scoring
Flue gas recycle and O2 mixing (for PC)	Flue gas recycle system	Flue gas recycle fan, reheat depending on T of recycle, O2 preheater	Gross PG level (MWe)	0.1-1MWth	30MWth	250MWe
	O2/Fluegas mixing system		Gross PG level (MWe)	eq. 0.1-1MWth	eq. 30MWth	eq. 250MWe
	O2 supply to burner or grid	Different technologies are under development for O2 supply to burner and burner gas streams. Differences are due to technology, different design philosophy depending on supplier. Different designs to be tested	Gross Power (MWth)	-	eq. 30MWth	eq. 40MWth

Oxyfuel – capacity and performance (3/3)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Flue gas treatment and cooling (for PC)	DeNOx	Current technology to be improved with respect to needs of downstream steps for NOx, SOx, dust, trace elements ESP and/or baghouse depending on fuel	Gross PG level (MWe)	0.1-1MWth	30MWth	250MWe
	Flue gas desulphuri-zation					
	Particle removal before recycle					
	Flue gas condenser	Water separation		0.5MWth	30MWth	250MWe
CO_2 treatment (for PC)	CO_2 purification	Depending on compression technology, transport (corrosion?), storage option (geology), different limits to be considered (N2, O2, NOx, SOx, H2O, trace elements, dust)				
	Compression train	Supercritical compression	Gross PG level (MWe)	-	30MWth	250MWe
Overall process	Flexibility	Plant flexibility to increase positive commercial & technical impacts : e.g. enabling dual air & oxy modes				
	Process integration	Load change flexibility, start up, shut down and partial load behaviour of all components which are highly dependent on each other				
	Low grade heat use	Recovery of waste heat from ASU or CO_2 compression in steam cycle				

Post-combustion technology blocks – current validation status and expected evolution



Scope of technology blocks for Post-combustion – capacity and performance (1/6)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Fuel preparation	Drying	Lignite	Capacity (t/h)	15	c.100	c. 100
		Biomass	Share of cofiring by mass (%)	?	20	20
CO_2 enrichment in flue gas	Flue gas recycle (FGR)	FGR system should be working in the scope of actual GTCC products, GT efficiency, lifetime and dynamic response; FGR connection to GT blowers and piping	SC Gross power (MWe)			266
			SC Gross efficiency (%)			36.6
			CC Gross power (MWe)			418
			CC Gross efficiency (%)			57.5
			Lifetime vs. corrosion (kEOH)			24
			Flue gas recycle ratio (%)			30-40
			System pressure loss (mbar)			20
			Operating window (ratio)			[0;40]
	Supplemen-tary firing	Supplementary firing to use all O2 available before HRSG	Exhaust O2 mol fraction	Proven		3-8
			Exhaust temperature (°C)	Proven		>1500
			Turbine exhaust mass flow	Proven		

Scope of technology blocks for Post-combustion – capacity and performance (2/6)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Fuel combustion	Gas turbine	Liquid/gas fired air combustion, GT combustor chamber	Gross power (MWe)	266	340	340
			Efficiency (%) (NGCC)	36.6 (57.5)	-	-
	Pulverized fuel	Dry/Raw lignite	Gross power (MWe)	200/1,000	200/1,100	200/1,100
		Bit. coal	Gross power (MWe)	900	1000	
	CFB	-	Gross power (MWe)	340	460-600	460-600
Steam cycle	Steam generator	Highest available efficiency is recommended for CCS	Efficiency for lignite (% LHV)	43	43	48
			Efficiency for coal (% LHV)	43	45	46 (50% if 700°C)
	Steam turbine	LP steam extraction to supply CO2 scrubber	Steam temperature (°C)	580/600	600/620	600/620 (700 ?)

Scope of technology blocks for Post-combustion – capacity and performance (3/6)

Technology blocks	Technology	Scope	Performances: Parameters	Performances: Proven performance	Performances: Expected by 2012	Performances: Flagship demo
Flue gas treatment and heat recovery	Power	For amine capture technologies needs, usage of optimum desulfurization technology required (for economic reasons) Desulfurization down to the measurement limits (c.1ppm) has been demonstrated with 660MW. DeNOx <0.5ppm has been demonstrated as well. For Alstom chilled ammonia scrubbing state-of-the-art is (more than) sufficient. Current state-of-the -art NOx levels are sufficient for CO_2 scrubbing. Particulate levels as after Wet ESP are ok.	Gross power (MWe)	660	1,000	Adjusted to techno
	Flue Gas De-sulphurization		SOx concentration in flue gas (ppmv)	<1 (increased pressure drop)	<1 (optimized pressure drop)	<5 (optimized pressure drop)
	Particulate removal		Particulate matters level (mg/Nm3)	10-20	10-20	-
	DeNOx		NOx concentration in flue gas (ppmv)	<0.5	<0.5	Adjusted to techno

Scope of technology blocks for Post-combustion – capacity and performance (4/6)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
CO_2 capture	Amine	Basic assumptions: 1)removal rate for coal: c.20t/d and MW, removal rate for gas c.10t/d and MW, 2)min power level calculated on this basis, 3)Power level defined for CO2 capture process can also be slipstream	Removal rate (t/d) (400MWe appr. 7500tpd)	25 (CASTOR)	75 (NGCC); 200+ (coal)	-
			Removal rate (%)	-	90%	>90%
			Gross power (MWe)	2	10	>100
	Ammonia		Removal rate (t/d)	-	60 (NGCC); 200+ (coal)	-
			Removal rate (%)	-	90%	>90%
			Gross power (MWe)	0.25	10	>100
	Other physical absorption		Removal rate (t/d)	10	-	-
			Removal rate (%)	-	-	>90%
			Gross power (MWe)	?	?	>100
	Scrubbing with solids (carbonate loops, others)	Assumed not available in Flagship Demo time frame, need further RD&D				
	Membranes					

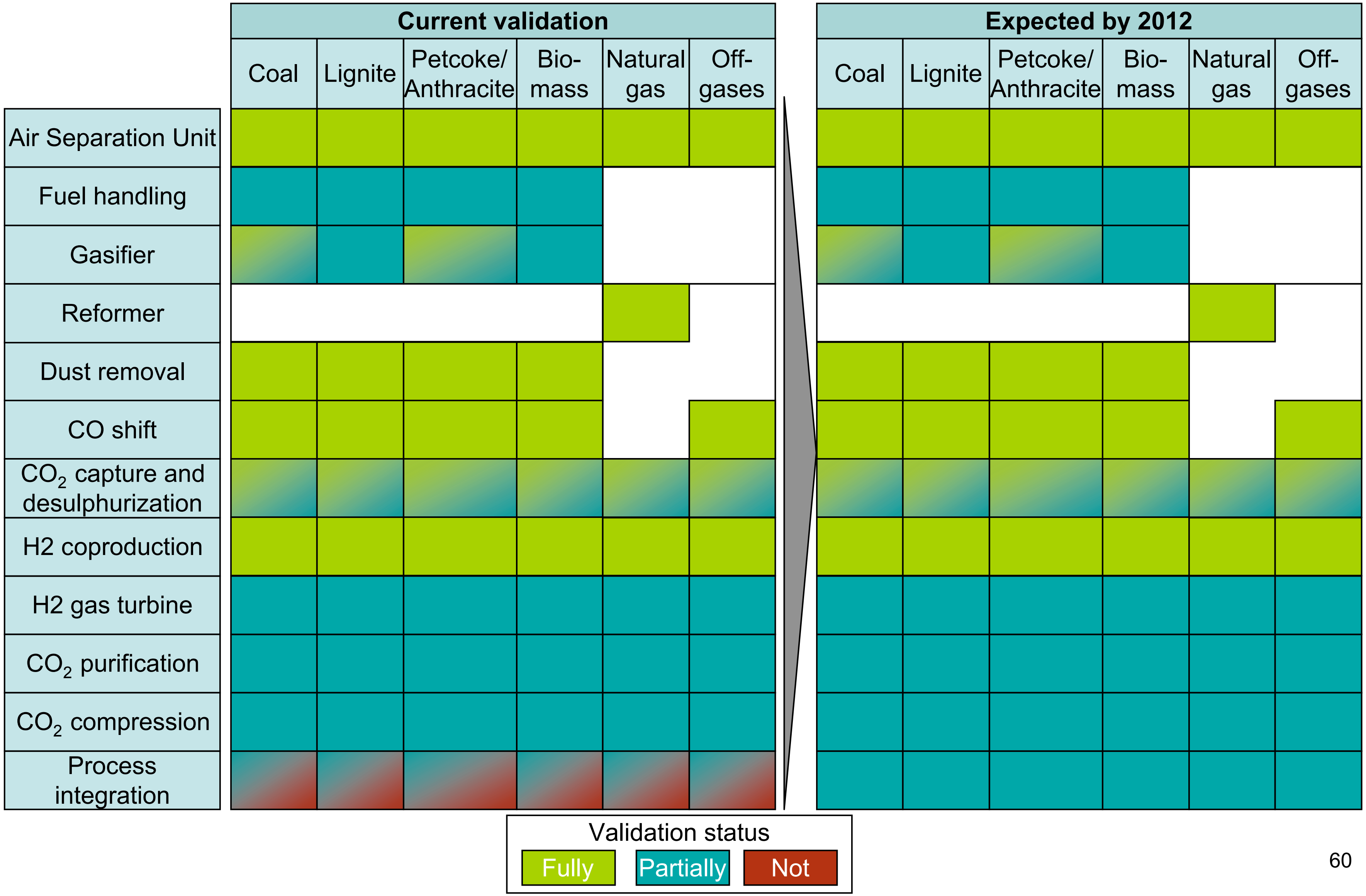
Scope of technology blocks for Post-combustion – capacity and performance (5/6)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
CO_2 treatment	CO_2 purification	Depending on compression technology, transport (corrosion?), storage option (geology), different limits to be considered (N2, O2, NOx, SOx, H2O, trace elements, dust)	Capacity (t/d)	3,000	6,000	>1,000
			Quality	Food grade quality	Legal limits	Directive s.2012
	CO_2 compression	to produce supercritical CO2; for 100MW coal plant 25kgCO2/s is sufficient	Capacity (kg/s)	85	170	Adapted to plant

Scope of technology blocks for Post-combustion – capacity and performance (6/6)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Overall process	Power loss compensation	Net power Loss Compensation and flexibility can be discussed to increase positive commercial and technical impacts. Ex: Enabling dual oxy and air combustion.	Level of integration	None	Partial	Fully
			Penalty of retrofit (%)	30	-	-
	Process integration	Load change flexibility, start up, shut down and partial load behaviour of all components which are highly dependent on each other	Minimum Load (%)	-	-	70 per train
			Emergency shutdown behavior	-	-	No impact
			Load change velocity (%)	-	-	50% of non capture plant

Pre-combustion – detailed expected evolution of validation status



Scope of technology blocks for Pre-combustion – capacity and performance (1/5)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Air Separation Unit	Cryogenic train	Single train integrated with F class turbine proven. Air and N2 integration levels determine ASU concept and overall efficiency. Development required for higher distillation & Oxygen pressure levels. Fuel independent. Integration of compressor drive system to be considered	Capacity (t/d) 0% - 50% air side integration considered. Higher levels of integration feasible.	4,300	7,000	Demos will stick to single train concept. (2 or 3 turbines on one ASU - not proven. But is a matter of RAM vs, CAPEX. Start up part load may be an issue)
	Membranes	Membranes ASU assumed not available in Flagship demo timeframe				
Fuel handling	Fuel drying, grinding and mixing	Fuel pre-treatment particularly for fuels with high water content or difficult to grind to size required for feeding to gasifier (lignite, biomass). For more variable fuel feed online fuel analysis required.	Capacity (t/d)	WTA pilot plant 600t/d DWT test plant for lignite	600t/d	2500-7000 t/d Improvement in integration to enhance efficiency

Scope of technology blocks for Pre-combustion – capacity and performance (2/5)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Gasifier	Fuel dry feeding	Relevant for high overall efficiency.	Capacity (t/d)	2,500-7,000	-	2,500-7,000
	Gasifier optimized for CCS	Energy and cost optimized system targeting high carbon conversion rate and CO shift. Very fuel specific - e.g. ash melting point, ash content, reactivity. Steam integration to be adapted in CCS layout. Operational flexibility for capture and non capture mode.	Capacity (t/d)	-	7,000	-
			Type	raw gas cooling or full quench - both not 100% suited for process with CO-shift	-	dry feed system with partial or full water quench optimised for efficient integration of CO shift
Reformer	Capacity proven. Integration in water steam cycle is relevant and very IRCC specific		Integration in Water Steam Cycle			
Dust removal	Depending on gasifier concept. Venturi wash, ceramic filter or metal filter. Relevant are primarily availability, then CAPEX, O&M and pressure loss. Availability issues with some types. Adsorbents for mercury capture may gain importance.		Operating temperature (°C)	~250-300	-	~250-300

Scope of technology blocks for Pre-combustion – capacity and performance (3/5)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
CO shift		Optimized plant integration of steam production and steam / water demand. Size for F-class engine supply is proven. Sour or sweet shift - depending on concept for desulphurization and specification for delivered CO2.		Proven in full scale in chemical industry, advanced integration to be proven		Advanced thermal integration concepts to be proven.
CO_2 capture and de-sulphurization		Can be combined with desulphurization or separate. Based on absorbtion. Membrane processes not expected to be commercially available until 2015. Optimized for IGCC application (heat integration, pressure levels). Rest sulphur content dependent on GT requirements and NOx limits (SCR fouling from SO3 based aminosalts). CO-Shift requirements relevant. Some fuel specific aspects: sulphur content, chlorides, hazardous compounds.	MDEA, RECTISOL, Selecsol, Genosorb, ... (other processes not expected in full scale) Optimization with regard to heat requirement, presure loss, consumtion of catalysts, aux.-power. Quality of delivered CO2	CO2 capture not proven in IGCC environment	-	Integration in IGCC to be proven
H2 coproduction		Avoid N2 and steam feed into the fuel gas stream.Adapted fuel feed system. Meet pressure requirements for H2 process.	downstream for 99,999% purity PSA required - proven			Very few references based on solid fuels

Scope of technology blocks for Pre-combustion – capacity and performance (4/5)

Technology blocks	Technology	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
H2 GT	F class gas turbine	Syngas and hydrogen rich gases are diluted with waste nitrogen and/or steam to comply with combustion requirements. High dilution levels have been proven already in the nineties. However there is some rationale for reduced dilution levels in terms of efficiency and cost. Optimization efforts are under way for high availability, efficiency, low NOx emissions.	-	small GT <50 MW are proven with Hydrogen contents up to 80%. F-class engines are proven with dilution.	-	Modern higly efficient F-class turbines >300 MW
CO2 purification	Depends on CO2 capture process on one hand and requirements from compressor train and transport and storage infrastructure on the other hand. Can be a major issue depending on solvent technology. Uncertainties with regard to regard to requirements. Topic is common to oxy-fuel and post-combustion. However it should be easier to comply in pre-combustion with upstream purification in place.		Depending on requirements: H2O, SO2, H2S, CO, ...	According to ENCAP WP 1.1 requirements are fulfilled in per-combustion capture	-	Final purification could be required for some contaminants according to CO2 specification

Scope of technology blocks for Pre-combustion – capacity and performance (5/5)

Technology blocks	Scope	Performances			
		Parameters	Proven performance	Expected by 2012	Flagship demo
CO_2 compression	Multi stage compression. Pressure ratio validated. Considerable upscale required (factor 3-4). Plant integration of intercooling. Corrosion resistance. Control concept. Drive concepts other than electrical to be considered. Topic is common to oxy-fuel and post-combustion. However it should be easier to comply in pre-combustion with upstream purification in place	Pressure level 100 - 200 bar	Weyburn project:, single train multi shaft compressor, ebd pressure 187 bar, 60000 m^3/h, 13,5 MW	-	Single train compressor, high efficiency, high availability, low O&M.
Integration	Overall plant not be scaled below 350 MW net - has to match F-class gas turbines.Optimised balance of degree of integration and redundancy to achieve low life cycle cost and high availability.Covers multiple areas such as heat, N2, air, steam	Must not be judged on basis of net efficiency, but on LCC.	Proven in full scale in chemical industry	-	Target of the entire Flagship program is to reduce risk premium in EPC and thus foster market penetration

Scope of technology blocks for efficiency improvement – capacity and performance (1/3)

Technology blocks	Technology/ Main function	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Steam cycle	Overall efficiency could be increased by increasing steam parameters from category C to Category D		Turbine inlet pressure (bar)	275	350	350
			Temperature Main steam/Reheat (°C)	600/620	700/720	700/720
			Efficiency (% LHV)	46	50	50
Fuel combustion	Increasing efficiency would permit to decrease fuel consumption and CO2 emissions		Coal consumption	X	95% X	95% X
			CO_2 emissions	Y	95% Y	95% Y
Boiler	Pulverized coal		Gross power (MWe)		1,000	500
	Boiler efficiency		Efficiency (%)	95	?	?
	Water wall	Higher temperature into steam path requires new material for enclosing walls, heating surfaces, header and piping (e.g. Ni based alloy materials). Tubes made out of ferritic or austenitic steel cannot withstand higher temperature	100,000 hours of creep rupture strength (Mpa)	90-100	90-100	90-100
	Superheater		Resistance against high temperature corrosion			
	Reheater		Resistance against steam oxidation			

Scope of technology blocks for efficiency improvement – capacity and performance (2/3)

Technology blocks	Technology/ Main function	Scope	Performances			
			Parameters	Proven performance	Expected by 2012	Flagship demo
Boiler	Material welding	Welding of pipes with different material grade (P92, T24, A617…)	Welding qualification			
Turbine	Reaction	Reaction	Gross power (MWe)		1,000	500
	HP module	High steam temperature require Ni-based Alloy for inner casing and rotor. Rotor welding with different material grade is required				
	IP module					
	HP bypass valve	High steam temperature require the use of Ni-based Alloy is needed				
	Start-up valve					
	Stop valve					

Scope of technology blocks for efficiency improvement – capacity and performance (3/3)

Technology blocks	Technology/ Main function	Scope	Performances				
			Parameters		Proven performance	Expected by 2012	Flagship demo
Plant	Overall plant		Gross power (MWe)			1,000	500
	Material identification	High steam temperature requires new material for main steam path and hot reheat steam path. Using Ni-based Alloy is needed	100,000 hours of creep rupture strength (Mpa)		90-100	90-100	90-100
	Material qualification						
	Piping design						
	HP bypass valve						
	Piping flexibility	High steam temperature and pressure require high thickness Ni-based Alloy material. Flexibility must be taken into account piping routing					
	Plant layout	High cost Ni-based alloys require optimisation of the plant layout to limit the use of those materials					
Overall process	Process integration	Load change flexibility, start up, shut down and partial load behaviour of all components which are highly dependent on each other. Full integration required	Start up length (hours)	Cold			5
				Warm			3-4
				Hot			2

Main technology options to transport CO_2 captured in power plants

CO2 transportation

Onshore pipelines

- Already operational (>3,000 km worldwide, mainly in the US for EOR)
- CO_2 pipelines very similar to existing natural gas pipelines
- CO_2 transported in supercritical phase (100-150 bar)
- Densely populated area deployment issues

Offshore pipelines

- Offshore pipeline technology operational, as large natural gas pipelines have been built at depths over 2,000 meters

Shipping

- Comparable to ship transportation of liquefied petroleum gas (LPG)
- 4 small CO_2 ships already active, transporting liquefied CO_2 for food usage
- Limited capacity

Rail/truck tankers

- Already operational (CO_2 for beverage)
- Not considered as attractive option for large scale transport:
- Costly
  - Non compatible with GHG reduction goal
  - Very limited capacity

Source: IPCC, O&G Journal, IEA GHG, L.E.K. Analysis

Pipeline transport process explanation

Process	Initial compression →	Pipeline (← Booster/Pumping stations) →	Injection site
Description	• CO_2 is compressed over supercritical pressure (i.e. 75 bars), generally up to 100 to 150 bars • Compression also increases temperature to about 150°C • Cooling needed before transport	• Optimal CO_2 state is supercritical – Minimizes volume – Most "fluid" state: minimizes friction losses • Within pipelines, friction causes pressure loss: 4 to 15 bars per 100 km in most conditions • However, for large diameter pipelines, losses are limited and should not require booster stations – Weyburn (14 inches) loses 7 bars per 100 km – In normal conditions, larger pipelines should have limited losses	• Additional compression may be needed for storage, depending on formation characteristics and CO_2 usage (e.g. EOR)

Significant CO_2 pipelines already exist

Pipeline	Location	Operator	CO_2 flow *(Av. 000 t / d)*	Length *(km)*	Year finished	Origin of CO_2
Cortez	USA	Kinder Morgan	53	808	1984	Mc Elmo Dome *(largest known natural accumulation of pure* CO_2)*
Sheep Mountain	USA	BP Amoco	26	660	-	Sheep Mountain *(smallest CO_2 source field serving the Permian Basin)*
Bravo	USA	BP Amoco	20	350	1984	Bravo Dome *(natural CO_2 source with 225 Bn m3 reserves)*
Canyon Reefs Carriers	USA	Kinder Morgan	14	225	1972	Shell Gas plants *(natural gas processing plants)*
Val Verde	USA	Petrosource	7	130	1998	Val Verde Gas plants *(purification operations at 4 natural gas plants**)*
Bati Raman	Turkey	Turkish Petroleum	3	90	1983	Dodan Field *(natural resource of carbonates)*
Weyburn	USA & Canada	North Dakota Gasification Co.	5	328	2000	Gasification plant *(Synfuel Plant, which manufactures synthetic natural gas from lignite)*
Snohvit	Norway	Statoil	2	160	2006	Gas plants *(purification operations)*

Note: *98% purity level; **This CO_2 contains H2S contamination and is thus only suitable for use in sour gas fields
Source: Statoil, Sonatrach, IPCC, IEA GHG, DTI, DOE, L.E.K. Analysis

Pipeline construction process

Preparation	Pipe welding / coating / bending	Completion
		
• Pipeline itinerary is planned and permits granted • Right of way is cleared and terrain prepared • Pipe sections are brought along the pipe route • A trench is excavated (generally 1m deep)	• Pipes are welded along the pipe route • Coating is applied at the end of the pipes • Pipeline is bent to match geographic characteristics of the route (hills, curves, etc)	• Pipeline is lowered in the trench • Trench is filled and vegetation restored • For offshore pipelines, pipes are welded to the end of the pipeline on a barge, then lowered down to the seabed as the barge advances

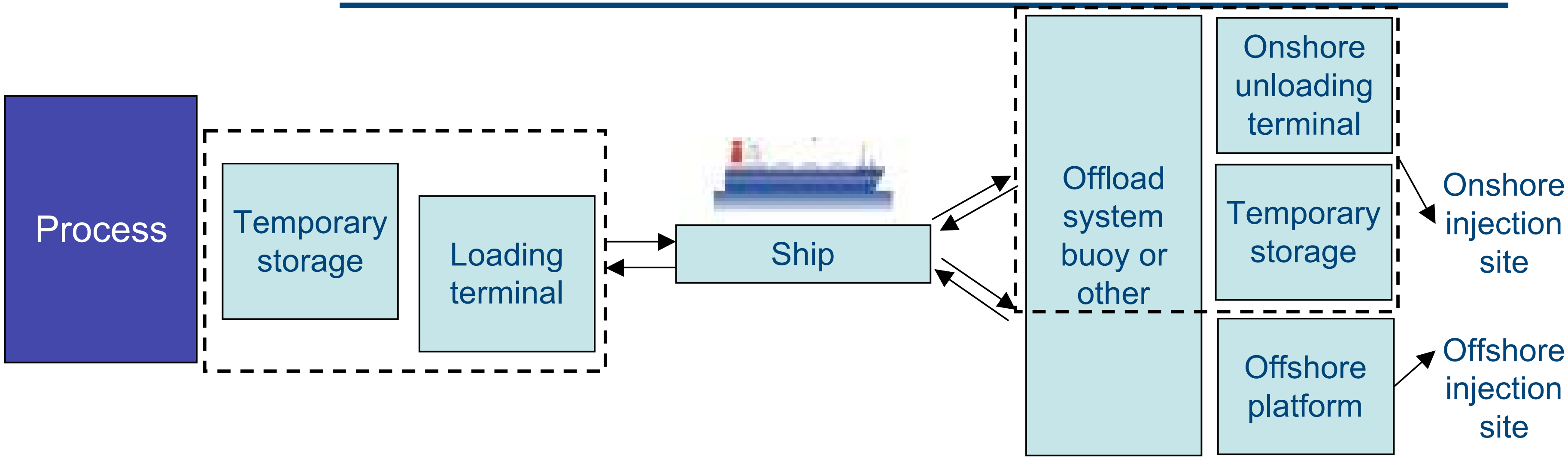
• Process well-mastered, potential issues in densely populated areas

Technical aspects of pipeline CO_2

Materials	• With appropriate CO_2 drying and purification, regular carbon steel can be used • Stainless steel can be used in some specific pipe sections to avoid corrosion
Pressure	• Natural gas is generally transported around 90-100 bars in large "backbone" pipelines (lower in small distribution pipelines) • Pressure range is comparable to what would be required for CO_2 transport (100-150 bars)
Monitoring	• Pipeline monitoring consists in supervision by personnel (on the ground or by air), by metering devices (pressure, temperature, etc) and periodic inspection by robotic "pigs" • Comparable for CO_2, with possible increase in frequency depending on local regulations

Equipment and processes very comparable to natural gas pipeline transportation

Transport processes explanation



Description

- Liquid CO_2 (-50°C and 7 bars) is temporary stored in tank to align continuous capture with discrete flow of ships
- Liquid CO_2 is charged to the ship with pump adapted to high pressure

- Liquid CO_2 is transported in ship
- Heat transfer from the environment through the wall of the tank will boil CO_2 and raise pressure
  - Necessity to refrigerated this gaseous CO_2 to liquefy it
- Return to loading terminal with tank filled with dry CO_2 gas

- Special offloading technology is developed for safe on- and offshore operations
- Unloading of the liquid CO_2 in temporary storage or directly on underground storage site
  - Additional compression may be required

Technical aspects of CO_2 transportation – ships

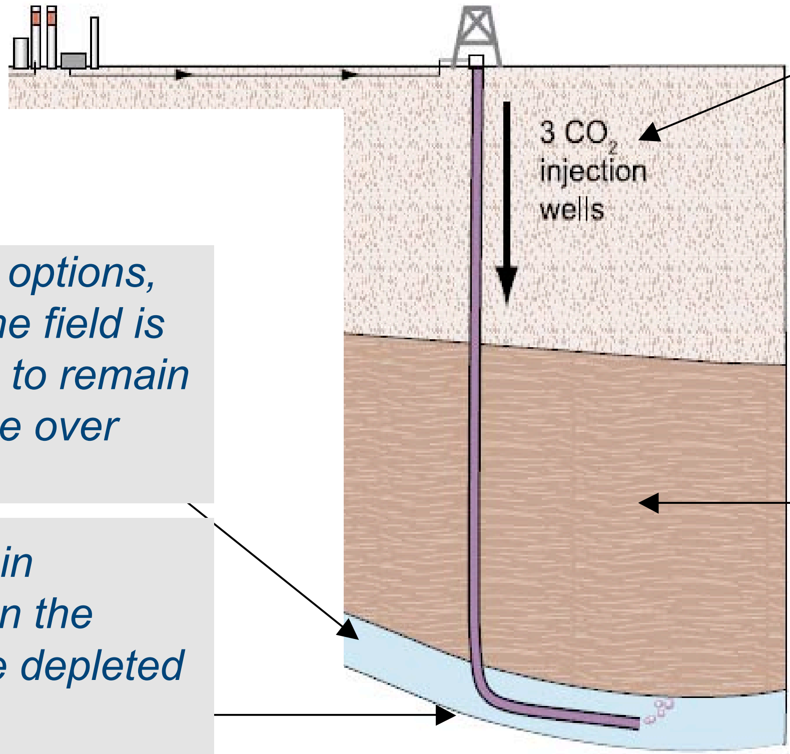
Characteristics of ship transportation		Comments
CO_2 phase and purity requirements	Liquid state at -50°C and 7 bars	• Comparable to semi-refrigerated LPG ships, but unlike large LNG tankers, which are around -160°C and atmospheric pressure
Maximum ship capacity	230,000 tonnes in a 200,000 m3 supertanker	• This would only cover between 20 and 25 days of CO_2 from one high-efficient 800MW coal plant
Technical maturity of ship transport	4 active ships (20,000 m3) Comparable to LNG tankers	• 4 small ships are in operation today, bringing food-grade CO_2 from plants to terminals in consuming regions • Latest LNG tankers carry over 200,000 m3; the same yards could build CO_2 tankers
Construction timing of a ship	2 years for large tankers	• Building time estimated between 1 and 2 years depending on ship size (closer to 2 years for supertankers)

CO_2 transportation ships built on the model of LPG tanker

Depleted oil and gas field storage process explanation

Schematic drawing of a depleted oil/gas field CO_2 storage site (In Salah project)

Processing facilities



Depending on acceptable injection rates and field characteristics, more or less injection wells will be required

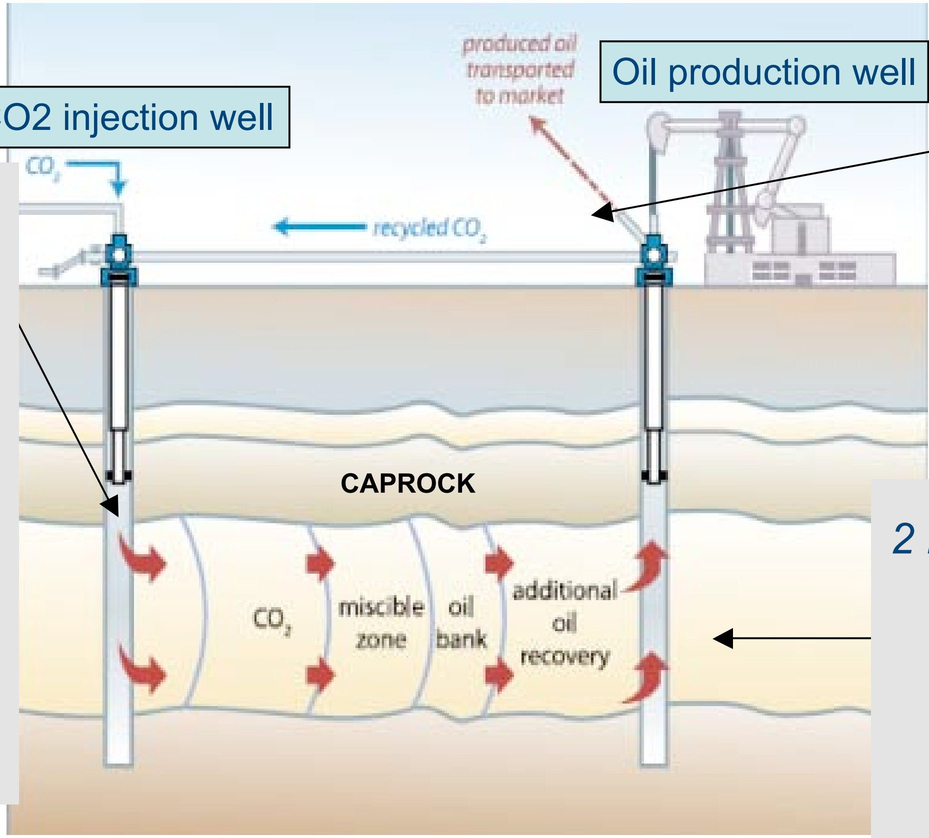
As for other storage options, minimum depth of the field is about 800m for CO_2 to remain in supercritical phase over 31°C

The CO_2 is injected in supercritical phase in the water, saturating the depleted oil and gas field

Site preparation and monitoring are particularly important for depleted fields, because oil production and abandoned wells can have created leakage risks

EOR/EGR process explanation

Schematic drawing of an EOR system
(followed by permanent storage) using CO_2



CO_2 is injected in a specific well, separated from the oil extraction well. Minimum optimal depth of the field is about 800m for CO_2 to remain in supercritical phase (natural earth temperature above 31°C at that depth).

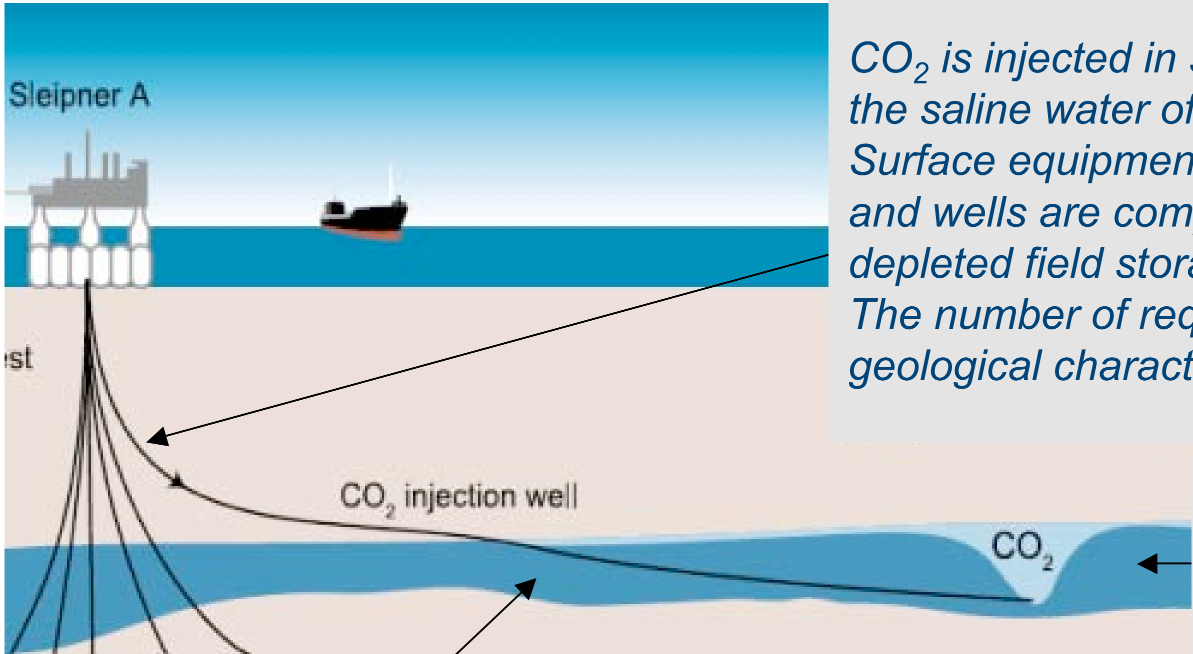
Part of the CO_2 stays in the oil formation, the rest being re-extracted with the oil and partly recycled.
Quantity of CO_2 staying in the formation depends on CO_2 and oil characteristics (20%-70%).

2 EOR mechanisms:

- *CO_2 "chases" the oil by flooding the formation*
- *In optimal temperature and pressure conditions, part of the CO_2 also dissolves in the oil (miscible zone), making it more fluid.*

Deep saline aquifers storage process explanation

Schematic drawing of Sleipner Utsira Formation deep saline aquifer storage site



CO_2 is injected in supercritical phase in the saline water of the aquifer.
Surface equipment, injection equipment and wells are comparable to EOR and depleted field storage.
The number of required wells depends on geological characteristics.

A deep saline aquifer is a permeable sedimentary rock formation saturated with water.
Depth is generally between 800m and 3 km.
Thickness and geological characteristics of aquifers (in particular permeability, which defines how “easily” CO_2 can enter) are highly site specific.

Significant uncertainty exists on the share of aquifer volume that can be filled with CO_2 (between 2 and 70% estimates), because the speed and importance of CO_2 dissolution and precipitation is not yet well known.

Scope of technology blocks for storage (1/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Basinwide Screening (site options) Outcome: ranked list of potential storage sites; ident of data and knowledge gaps								
Identify sedimentary basin, stratigraphical sequence	Standard industry systems	Identify the components that support storage (reservoir, seal, structure)	Having access to data that allows an evaluation of the principal components of a storage system and preferably a ranked assessemt of storage sites within a bsain.	Tools proven and in common industry use. Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accpeted practices (e.g. as in reserves assessment for petroleum and minerals). .	Alignment of peer reviewed work flows for screening	Documented and published screening procedures for each flagship demo Motivates the funding of the AQUACO2 project proposal under assesment by EU commission		but derestricted data access (e.g. Norway, Canada) is a prerequisite for screening activities beyond Flagship pgm. Restricted data access delays CCS implementation, and increases project risk.
Compile DATA		Seismic, wells, license, geography, petrophysical, fluid, pressure, current regulatory constraints; identify data availability and gaps						
Screen for STORAGE PROSPECT		For each storage site screen for capacity, injectivity and containment through structure, faults & fractures, cap rock, reservoir, pressure, fluids, mineralogy, legacy wells, sorrounding ressources, pottable aquifers, surface features						
Screen for STORAGE SYSTEM								
Storage System INTERACTION		Define the storage system in the context of other economic interst (Hydrocarbons/minerals), potable water, biosphere/marien biosphere, atmosphere (environmental, HSE, population)						
Shortlist of potential storage sites		Rank potential storage sites against capacity, injectivity and life-cycle containment criteria and demonstrate viable linkage to source						

Scope of technology blocks for storage (2/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Site Maturation (preferred sites)								
Evaluate Storage features	DATA avalibility is a key issue for all activities below		Confirm that the storage sites (s) is large enough to hold full life-cycle CO2 volumes. Sustained injection rates over the life-time of the project can be achieved. Model and predict distribution of CO2 in the subsurface and demonstrate credible mechanisms for long term containment.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices. Need to improve capability to predict caprock properties/continuity in areas with sparse data (charateristic for many aquifers). Need to be able to build a complete well model describing the wellbore integrity and flux rates. Reactive flow: Need modelling tools that fully couple all processes or can interface to specialised reactive flow modelling tools (e.g. Petrel, PVTsim which supply input to flow models)				
Seal	Standard industry systems Improve lab experiments and numerical modelling capacity	Evaluation the primary and ultimate sealing capacity of cap rock for CO2			Improved industry capability to evaluate cap rock properties and predict sealing potential an lateral continuity	Focus data acquisition strategies on improved undesrtanding of cap rock properties and begin shared database		
Faults and Fractures	Standard industry systems Improve capability to model CO2 flux through faults and fractures	Assessment of safe operation pressure envelope including safety margin for fracture propagation pressure, fault reactivation pressuree, fault valving pressure and seal capillary entry pressure which govern maximum safe bottomhole injection pressure			Alignment of peer reviewed work flows. Geomechanical capabilities become an integral part of project evaluation	Focus data acquisition strategies on improving geomechanical modelling capability		
Well integrity (existing wells)	Full wellbore integrity model; numerical model of wellbore geomechanics;tools to assess integrity of old/abandoned wells	Identify all old wells, location and condition of wells. Review well completion & abandonment reports, surveys, cement practice & zonal isolation. Summarise basin-wide well failure data (frequency and causes). Identify potentiall to re-enter to repair or abandon old wells.			Industry capability to build full wellbore model for integrity and to incorporate CO2 fluw rates into risk project asessement	Test emerging modelling capability and acquire real data to mature capability further.		

Scope of technology blocks for storage (3/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Reservoir capacity	Standard industry systems	Thorough estimation of primary and subsequent storage capacity including assement of structure, distribution of rock prpoerteis, flow behaviour and trapping mechanisms (single phase CO2, dissolution, residual trapping and mineral trapping)	Confirm that the storage sites (s) is large enough to hold full life-cycle CO2 volumes. Sustained injection rates over the life-time of the project can be achieved. Model and predict distribution of CO2 in the subsurface and demonstrate credible mechanisms for long term containment.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices. Need to improve capability to predict caprock properties/continuity in areas with sparse data (charateristic for many aquifers). Need to be able to build a complete well model describing the wellbore integrity and flux rates. Reactive flow: Need modelling tools that fully couple all processes or can interface to specialised reactive flow modelling tools (e.g. Petrel, PVTsim which supply input to flow models)	Alignment of peer reviewed work flows	Quantification of storage redundancy requirement and CO2 storage impact on regional aquifers		
Normal flow	Standard industry systems	Static and dynamic model of plume migration with time within primary reservoir and model migration within secondary containment system as part of risk scenarios. Assess flow sensitivities on plume extent and pressure distribution by varying input data (e.g. reservoir heterogeneity, fracture distribution, PVT. Assess potential for impact onto regional aquifer.			Alignment of peer reviewed work flows	Defining key sensitivities that constrain plume migration and pressure modelling. Publishing workflows for operational and extended time scales for modelling.		

Scope of technology blocks for storage (4/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Reactive flow (CO_2 + any contaminants)	Standard industry systems need integration with emerging modelling codes/databases to handle complex geochemical/geomechanical processes. Lab experiments with critical liquids at operating conditions.	Predictive modelling of time dependent processes and their impact on flow, capacity and containment (chemical and physical rock-fluid and fluid-fluid interaction)	Confirm that the storage sites (s) is large enough to hold full life-cycle CO_2 volumes. Sustained injection rates over the life-time of the project can be achieved.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices. Need to improve capability to predict caprock	Emerging consensus on key reactive flow issues and in which geological settings these may be significant. Improved interfaces between flow modelling simulators and specialised modelling tools.	Assess for reactive flow issues prior to site selection and acquire data during field demo operation and post-operation phase to validate reactive flow components		
Diffusion	Standard industry systems	Establish mechanisms and rates of diffusion through cap rock, faults/fractures wellbore annuli	Model and predict distribution of CO_2 in the subsurface and demonstrate	properties/continuity in areas with sparse data (charateristic for many aquifers). Need to be able to build a complete well	Alignment of peer reviewed work flows. More cap rock cores availabe for diffusion measurements and modelling	Focus data acquisition on cap rock cores and analysis	But cores missing	
Injectivity	Standard industry systems for natural injectivity - advances in compression and pumping technology required for some projects	Geo-system: Assesment of potential for sustained injectivity into the reservoir through asessment of critiacl pressures, reservoir heterogeneity, compartmentalisation, brine displacemnet, reactive flow and wellbore imparement. Engineered system: Sustained injectivity requires high up-time for compression/pumping equipment, pipeline, capture plant	credible mechanisms for long term containment.	model describing the wellbore integrity and flux rates. Reactive flow: Need modelling tools that fully couple all processes or can interface to specialised reactive flow modelling tools (e.g. Petrel, PVTsim which supply input to flow models)	Alignment of peer reviewed work flows. Increased data available on injectivity into aquifers			

Scope of technology blocks for storage (5/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Evaluate Leakage Potential			Confirm that the storage sites (s) is large enough to hold full life-cycle CO_2 volumes. Sustained injection rates over the life-time of the project can be achieved. Model and predict distribution of CO_2 in the subsurface and demonstrate credible mechanisms for long term containment.	Risk assessment methodologies are emerging at a project level that require regulatory consensus to move to standardised and accepted practices	Alignment of peer reviewed work flows. Consensus on main principles that underpin robust risk assessment. Emerging regulatory frameworks.	Full perfromance assessment of each demonstration project to include life-cycle containment risk assessment including risk mitigation strategies and clear linkage to monitoring and verification programme.		
Risk analysis	Adapted systems are emerging but as yet immature	Iterative assesment of major leak features that can be avoided through design and identification of residual risk to design a monitoring and verification plan and mitigation strategy. Agree performance with regulator.						
Features								
Events								
Processes								

Scope of technology blocks for storage (6/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Define Storage License Parametres		Identify a site or a combination sites which can contain the full life-cycle project CO2 volume.	Defining the boundaries of the storage complex and agreeing operating performance with regulatory bodies	Within Europe all current activities operate license exceptions from existing regulations on a project-by-project basis.. Only some of these projects have defined lateral and vertical boundaries prior to commencement	Increased project base with agreed license parameters and emerging national regulations	Documented and published criteria for regulatory definition of project boundaries for each flagship demo in order to establish first regulatory practice		
Identify containment boundaries	Interplay between Regulations (emerging) and storage system modelling	Define and agree vertical and lateral boundaries for a licensed containmnet complex wirth regulatory authorities						
Define separation distances		Define spatial and temporal separation margins between CO2 plume and identified leak features or sensitive zone (e.g. potable water, other licenses or national boundaries)						
Define operation volume		Agree licensed volume and pressure with regulator.						
Define operation pressure								
Define baseline M&V requirements	Standard industry systems combined with standard surface monitoring technologies and emerging technologies (e.g. marine biosphere)	Demonstrate geological storage of CO2 is effective and poses no unacceptable HSE or economic risk. To be effective this has to be against an agreed baseline. Setting external conditions informed by a combination of risk assessment, regulatory requirements and external stakeholder expectation (NGO, public).	Defining the baseline work and the monitoring & verification programme, including thresholdts for monitoring and inventory. Set the criteria for closure and agree post-closure monitoring with the regulator.	Not yet consensus on definition of a baseline for CO2 M&V. Extensive and mature toolkit exists, but no standards for M&V requirements (accuracy, areal extend, frequency)'. Criteria for definition of post-closure phase poorly defined. Different M&V requirements for storage security, HSE and ETS credit.	Alignment of baseline definition of storage system, particularly around threshold. Need for consensus regarding the key parameters for monitoring and verification	Integrate M&V procedures and plans as part of full storage system approach, showing clear linkages to risk assessment, containment, safe operation and CO2 credits.	Ok for weismic, wellbore and petrophysical, not for surface baseline & CO2 monitoring	But need integration with definition of thresholds and project economics

Scope of technology blocks for storage (7/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Site Testing								
Site Maturation Plan								
Data acquisition maturation planning	As per 'Evaluate Storage Features' above	Iterative loop of site maturation activities to close data gaps and mature prefered site(s)	Confirm that the storage sites (s) is large enough to hold full life-cycle CO2 volumes. Sustained injection rates over the life-time of the project can be achieved. Model and predict distribution of CO2 in the subsurface and demonstrate credible mechanisms for long term containment.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices.	Lack of subsurface data will limit maturation of some potential sites by 2012	Will take place on data rich sites/areas or sites with accelerated data acquisition and appraisal activities		
Baseline surveys (MMV)								
geosphere hydrosphere biosphere atmosphere	Standard industry systems combined with standard surface monitoring technologies and emerging technologies (e.g. marine biosphere)	Establish initial conditions for all storage system components and map fluxes (if any) for each domain	Determine the parameters and thresholds of measurements per domain and to establish the project reference baseline which will be used for future performance validation.	Tools exist today for general application, but CCS thresholds and parameters have yet to be established	Application of tools modified to CCS activities. Convergence on thresholds and key parameters, and recognition of technology gaps.	Agreed baseline executed and shared for all flagship projects; matching thresholds and parameters to regulator expectations		

Scope of technology blocks for storage (8/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Storage site and CO2 source integration		ability to model variability						
CO2 flow stream variability	# CHECK	Matching of time dependent variable CO2 output (rate and composition) to transportation and storage facility, including flow regime, phase envelopes, compression/pumping and operating envelope.	Constraining the time dependent flow rate of CO2	# CHECK	# CHECK	# CHECK		
CO2 composition	# CHECK		Constraining the time dependent composition of CO2 and contaminants	# CHECK	# CHECK	# CHECK		
CO2 phase behaviour	# CHECK		Establishing the operating envelope for transport, compression and storage	# CHECK	# CHECK	# CHECK		
Existing wells								
survey/monitor for leakage & corrosion	Existing technologies for live/suspended wells with a need for more sensitive and diagnostic tools for wellbore integrity. Lack of full wellbore modelling technology.	Identify any wells or zone that might be impacted by injected CO2 and establish a workover/abanonment plans	Establish a basis for evaluation of leakage potential from old wells. Setting standards for remediation and/or abandonment.	Toolkit for live/suspended wells	Numerical modelling capability for full wellbore and improved downhole diagnostics for wellbore integrity. Emerging consensus on whether to remediate poorly abandoned wells or design site to avoid plume contact.	Gather data that will support full wellbore modelling and provide reference welbore integrity data. Need to share experience between demonstration projects (i.e. through IEA Wellbore Integrity network)		
remediate or abandon	Existing remediation and abandonment standards require updating for CCS			Industry standards for production /injection operations (hydrocarbon development)	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.	For CCS	

Scope of technology blocks for storage (9/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Baseline Monitoring and Verification								
Identify M&V parameters and thresholds for each domain for a specific storage system								
HSE	Standard industry systems combined with standard surface monitoring technologies and emerging technologies (e.g. marine biosphere)	Safeguarding the environment, population and work force	Agree with regulators the parameters and thresholds and frequency of measurements.	Tools exist today for general application, but CCS thresholds and parameters have yet to be established	Application of tools modified to CCS activities. Convergence on thresholds and key parameters, and recognition of technology gaps.	MV programme agreed with regulator. executed for all flagship projects; monitoring results shared amongst all ZEP demonstrators (e.g. through IEA Monitoring Network)		
Containment		Setting performance standards and operating practices with regulatory bodies						
Verification		Assuring credit under the EU ETS and any national system. Verification that CO2 storage operation does not expose operator to external liability (e.g contamination of ground water, other operator's hydrocarbons)					For free phase CO2	
Forward Model Leakage - 'what ifs' for								
Atmosphere	Standard industry systems	Modelling plume migration beyond primary seal to identify leakage pathways to other domains. The intent is to mature M&V programme and demonstrate storage system integrity.	Model and predict distribution of CO2 in the subsurface and demonstrate credible mechanisms for long term containment.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices.	Alignment of peer reviewed work flows that demonstrate leakage pathways and secondary containment capacity (storage security)	Forward model leakage beyound the primary containment to fully identify leakage pathways and so mature M&V strategy.	For infividual storage system component but not for whole system	For primary containment but not for entire storage system
Biosphere								
Hydrosphere								
Geosphere								

Scope of technology blocks for storage (10/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Economical screening of MMV programme	Work process	Place economic constraints on M&V programme in the operation phase and to agree with regulator structures for M&V post-closure	Site-specific requirements against corporate screening criteria and project economics	Existing industry approches to economic screening require adaptation to extended CCS project time scales and to emerging EU and national regulations.	Formative screening models at a project-by-project level constrained by emerging regulations	Systematic economic screening, shared through IEA networks		
Regulatory MMV requirements	Regulatory dialogue and approval	Define MMV plans with regulators (features, accuracy, time) for all phases of project	Capability to work with regulators to shape regulatory requirements for MMV incorporating and adapting experience from active CCS and other relevant projects (e.g. natural gas storage, waste water injection)	Exist for oilfield operations but not matured for CCS	Adapted procedures to fit CCS and as licensed by national regulators deriving monitoring guidelines from CO2 Storage Directive	Develop common approach to future CCS project MMV requirements based on experience from flagship programme demos		
Define requirements for forward modelling based on MMV data.	Work process	Agree long-term modelling programme supported by M&V data that demonstrates performance (storage security) against agreed baseline, to guide future choice of tools and frequency of measurements.	Model and predict distribution of CO2 in the subsurface and demonstrate credible mechanisms for long term containment.	Modelling capability proven today but modelling capacity for full storage system limits capabilty	Increased modelling capacity and alignment on the requirement to model beyond primary containment	Forward model leakage beyound the primary containment to fully identify leakage pathways and so mature M&V strategy.	But modelling capacity constrain	But only sparsely applied to date

Scope of technology blocks for storage (11/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
OPERATION								
Design wells	Standard industry systems working to revised standards. Increased emphasis on material selection, cementing practices, zonal isolation and contracting and procurement standards	Establish design criteria for injection (and observation) wells (well geometry, completion intervals, materials choice,cement and cementing practices, contracting and tendering procedures - in line with life-cycle containment objectives.	Establish agreed design standards and contracting and procurement practices for sequestration wells	Industry standards for production/injection operations (hydrocarbon development); emerging practices for CCS activities	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		
Locate injecton wells + patterns	Standard industy systems	Siting injection wells to allow even distribution of CO2 in subsurface, providing separation distance from recognised leak features and including redundancy injection capacity to optimise operational flexibility	Model injection patterns to assure an even distribution of CO2 in the subsurface and manage pressure distribution within licensed limits	Industry standards for production/injection operations (hydrocarbon development);	Alignment of peer reviewed work flows/criteria for locating wells and defining injection patterns	Documented and published work flows/criteria for each flagship demo		
Remediate and/or abandon old wells	Standard industry systems working to revised standards.	Minimise risk of CO2 migration outside containment system by remediating and/or abandoning old wells to a revised CCS standard	Workover and or abandon existing wells; assure integrity to revised standards.	Industry standards for production/injection operations (hydrocarbon development);	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		

Scope of technology blocks for storage (12/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Drill & complete wells	Standard industry systems working to revised standards.	Drill and complete injection (and observation) wells to revised CCS standards	Drill and complete wells to revised standards; acquire adequate baseline data to monitor life-cycle integrity.	Industry standards for production/injection operations (hydrocarbon development); emerging practices for CCS activities	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		
Cement integrity and zonal isolation	Standard industry systems working to revised standards.	Demonstrate wellbore material and cement integrity and effective zonal isolation	Assure cement integrity and zonal isolation to revised standards	Industry standards for production/injection operations (hydrocarbon development) - large variations in operating standards and practices resulting in variable but widespread well integrity issues	Revised standards for CCS activities adressing extended storage life requirement; revised regulatory requirements for contracting and procurement procedures for CCS activities (integrity assurance not cost driven)	Documented and share cement and zonal isolation practices for each flagship demo through appropriate networks		
Manage near-wellbore clean-up	Standard industry systems working to revised standards.	Maximise injectivity without compromising wellbore integrity	Clean-up the near well-bore region to: -optimise injection capacity -minimise well integrity problems -not compromise containment -condition the near well bore region for CO2 injection (if required)	Industry standards for production/injection operations (hydrocarbon development); emerging practices for CCS activities	Alignment of peer reviewed practices and work flows	Documented and share near-well bore clean-up practices for each flagship demo through appropriate networks		
Inject dense phase CO2	Standard industry systems working to revised standards & potentially extending existing operating envelopes.	Initiate injection activities within the agreed operating envelope	Inject dense phase CO2 within licensed limits and across selected injection intervals	Capacity at the scale of existing demonstrator projects and within restricted operating envelopes	Alignment of peer reviewed practices and work flows	Document and publish practices for each flagship demo		

Scope of technology blocks for storage (13/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Manage injection P + T	Standard industry systems working within agreed licensed limits	Maintain injection activities within the agreed operating envelope	Confirm and maintain injection within licensed limits and across selected injection intervals	Industry standards for production/injection operations (hydrocarbon development); emerging practices for CCS activities	Alignment of peer reviewed practices and work flows	Document and share PT management practices for each flagship demo through appropriate networks		
Manage CO2 input into reservoir	Standard industry systems adapted to the variable throughput from different CCS projects	Maintain CO2 flow within defined operating envelope						
rate	Standard industry systems working within agreed licensed limits and adapted to the variable throughput from different CCS projects	Manage plant load variation as part of reservoir management strategy to maintain down-hole pressure control. Model near-wellbore effects.	Forward model and manage/optimise variations in CO2 throughput into subsurface	Emerging practices for CCS activities but not yet across a wide-range of operating scenarios	Alignment of peer reviewed practices and work flows	Selection of demos across a range of operating envelopes; document and share subsurface CO2 mangement practices for each flagship demo through appropriate networks		Not validated for specific demonstratotr types with highly variable throughput
areal and vertical distribution	Standard industry systems	Model plume distrubution and manage injection patterns/intervals to ensure en even distribution of CO2 vertically (i.e. in layered reservoirs) and laterally (i.e. even distribution of plume under cap)	Monitor injection intervals and plume migration/ pressure evolution within reservoir	Emerging practices for CCS activities but not yet across a wide-range of operating scenarios				

Scope of technology blocks for storage (14/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Lifecycle well integrity assurance								
logging	Standard industry systems but with more sensitive and diagnostic downhole tools for wellbore integrity	Logging well/cement integrity during the operational period to identify workover/maintenance requirements	Utilise sensitive and diagnostic downhole tools for wellbore integrity, conduct numerical model of leakage for a full well bore; develop a statistical basis for the evaluation of wellbore performance	Standard industry logging capabilty but with limited capability/experience in modelling full wellbore integrity - including flux rates	Numerical modelling capability for full wellbore and improved downhole diagnostics for wellbore integrity.	Gather data that will support full wellbore modelling and provide reference welbore integrity data. Need to share experience between demonstration projects (i.e. through IEA Wellbore Integrity network)		
workovers	Standard industry systems working to revised standards.	Execute workover activities and mangage simultaneous operations (SIMOP's)	Workover and or abandon wells; assure integrity to revised standards.	Industry standards for hydrocarbon development and CO2 EOR; little/no experience for CCS activities	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		
maintenance	Standard industry systems working to revised standards.	Manage existing well stock	Maintain existing well stock and ensure data quality to assess integrity against agreed baseline	Industry standards for hydrocarbon development and CO2 EOR; little/no experience for CCS activities	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		

Scope of technology blocks for storage (15/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Select wells near injection end-life cycle	Standard industry systems working within agreed licensed limits	Determine appropriate number and distribution of wells to convert to obsevation wells	Forward model plume distribution and determine appropriate wells to convert to observation wells	Adapted modelling workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices; absence of regulatory definition of post-closure observation well standards	Emerging consensus on key forward modelling issues and on emerging regulatory requirements.	Clarify and share license requirements/criteria for observation wells. Execute forward modelling prior to selection of abandonment/observation wells. Aquire data late injection period to modelling and selection.		
convert to observation	Standard industry systems working to revised standards.	Workover selected wells and convert to observation wells	Workover and convert wells; assure integrity to revised standards.	Industry standards for hydrocarbon development and CO2 EOR; emerging experience for CCS activities	Revised standards for CCS activities adressing extended storage life requirement	Incorporate experience to date from active demonstrator projects. Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		
abandon to agreed standards	Standard industry systems working to revised standards.	Abandon remaining well-stock to revised standard	Abandon wells; assure integrity to revised standards.	Industry standards for production/injection operations (hydrocarbon development);	Revised standards for CCS activities adressing extended storage life requirement	Review and update corporate standards for CCS activities, providing input for updated regulatory standards and practices.		

Scope of technology blocks for storage (16/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Storage Closure	Closing down injection and facilities leaving only monitoring equiment in place. It is anticipated that post-injection monitoring may be required for as long as the injection period (i.e. 30-40 years) or shorter if stability can be proven							
Define at end-of-injection								
CO2 plume position	Standard industry systems	Estsblish reference against which future CO2 dense phase plume is to be held.	Establish refence point for future comparison.	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices. Reactive flow: Need modelling tools that fully couple all processes or can interface to specialised reactive flow modelling tools (e.g. Petrel, PVTsim which supply input to flow models)	Alignment of peer reviewed work flows	Defining key sensitivities that constrain plume migration and pressure modelling. Publishing workflows for operational and extended time scales for modelling.		
Establish 'baseline' for all monitoring parameters		Make full inventory of all monitored parameters						

Scope of technology blocks for storage (17/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Histrory matching and forward models	Standard industry systems need integration with emerging modelling codes/databases to handle complex geochemical/geomechanical processes. Lab experiments with critical liquids at operating conditions.	Match against performance histrory and forward model plume behaviour and fate of CO2 dissolved in brine. Model 'what if' scenarios.	Use accumulated performance experience over 20-30 years for history matching and make predictions for the post-injection monitoring period as well as long term (100 to 1000's of years)	Adapted workflows are emerging at a project level but require peer review and alignment to move to standardised and accepted practices. Reactive flow: Need modelling tools that fully couple all processes or can interface to specialised reactive flow modelling tools (e.g. Petrel, PVTsim which supply input to flow models)	Emerging consensus on key forward modelling issues and on emerging regulatory requirements.	Assess for reactive flow issues prior to site selection and acquire data during field demo operation and post-operation phase to validate reactive flow components		
Define criteria for operator's obligations	Regulatory dialogue and approval	Define convergence and stabilisation criteria with regulators; i.e. when can operator leave site	Define criteria for containment of CO2 within storage system	Criteria for definition of post-closure phase poorly defined. Different M&V requirements for storage security, HSE and ETS credit.		Obligations agreed with regulator. executed for all flagship projects; monitoring results shared amongst all ZEP demonstrators (e.g. through IEA Monitoring Network)		

Scope of technology blocks for storage (18/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Observation wells	Standard industry systems working to revised standards.	Demonstrate wellbore material and cement integrity and effective zonal isolation	Assure cement integrity and zonal isolation to revised standards	Industry standards for production/injection operations (hydrocarbon development) ;	Revised standards for CCS activities adressing extended storage life requirement	Clarify and share license requirements/criteria for observation wells. Execute forward modelling prior to selection of abandonment/observation wells. Aquire data late injection period to modelling and selection.		
Perform regular MMV					Revised standards for CCS activities adressing extended storage life requirement	MV programme agreed with regulator. executed for all flagship projects; monitoring results shared amongst all ZEP demonstrators (e.g. through IEA Monitoring Network)		
geosphere	Standard industry systems combined with standard surface monitoring technologies and emerging technologies (e.g. passive seismic))	Review and updfate with regulators MMV activities (features, accuracy, frequency) and storage performance & security against agreed baseline.	Repeatedly determine monitoring parameters at specified thresholds of measurements per domain and compare to establish the project reference baseline for performance validation.					
hydrosphere								
biosphere								
atmosphere								

Scope of technology blocks for storage (19/19)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Work flow
Post Closure M&V								
CO2 containment M&V	Simplified standard industry systems combined with standard surface monitoring technologies and emerging technologies (e.g. passive seismic))	Define with regulators and certification agency need - if any - for long term monitoring to ensure storage integrity and collation of documentation	Identify robust method for scientific monitoring over the following decades	Some procedures emerging at pilot sites				
Termination procedure	Standard industry systems working to revised standards.	Removal of all surface and monitoring equipment, including any observation wells.	How to leave site	Exists in oil and gas operations	Revised standards for CCS activities adressing extended storage life requirement			
Relinquishment	Regulatory dialogue and approval	Specification of when and to what specifications the operator can return license area to the regulators	Hand-over of liability to regulator					

Scope of technology blocks for storage – ECBM (1/4)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Commercial	Work flow
Pattern test									
Evaluate Enhanced CBM production	5 spot pilot	In mature CBM field, which is in decline, a new injector is drilled or producer converted into an injector to conduct a 5 spot pilot. Here the main objective is to enhance the methane production and postpone the decline of the field. The CO_2 storage is a bonus.	Increase of methane production in producers	Technology to conduct pilot exists (Ref pilots in San Juan in 90s)	Commercially proven after pilot successfully completed in field (ready for scale up)	Successful pilot in mature field (stop decline in production and ready for scale up)			
CO_2 storage in coal	injection test	A depleted CBM well is converted into an injector to test CO_2 injectivity and storage potential of coal. The main objective is CO_2 storage	Prove long-term injectivity of CO_2: reduction in injectivty may mean less CO_2 can be stored)	Technology to conduct pilot exists (RECOPOL pilot, etc.)	Commercial concept depends on CO_2 credits and regulation	Successful injection in depleted field (continuous injection at acceptable rate and ready for scale up)			
Flue gas injection	lab evaluation followed by 5 spot test	The CO_2 footprint of a CBM operation is largely due to the own use (fuel gas) for compression. Capturing the flue gas and usage for ECBM may be attractive option to reduce own CO_2 at compressor stations. The effect of oxygen (in flue gas) on ECBM is unknown. Need better understanding before conducting field trails	Establish effect of oxygen on ECBM	not proven	Prove concept of flue gas injection	Ready to conduct commercial field pilot + integration with compressor sites			

Scope of technology blocks for storage – ECBM (2/4)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Comm ercial	Work flow
Upgrade facilities									
well site	space for CO2 equipment	If producer is converted to injector changes are required to well site	sufficient space, footprint	proven					
prevention corrosion	standard tech	CBM gas already contains CO2, but now more CO2 can be expected in produced gas (low pressure sep)	no corrision	proven					
CO2 separator	standard tech		efficiency separation process	proven					
New Facilities									
CO2 injection	standard CBM drilling	Volumes injected per well are relatively modest so low tech wells are sufficient	Completion of well	proven					
Well site	standard well site prep CBM	If new injector is drilled, new site needs to be prepared	space, footprint	proven					
CO2 transport	standard piping	Need to evaluate whether low pressure (plastic) or high pressure (steel) pipes will be used (compression at well-head or central compression)	pipe capacity + integrated design with compression	proven					
CO2 storage at site	CO2 storage tanks	CO2 storage buffer is required for pilot	Sufficient storage space to conduct pilot	proven					

Scope of technology blocks for storage – ECBM (3/4)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Commercial	Work flow
CO2 separation	standard tech	Extra separation may be required. Separation is possible and proven. Moreover, there are almost no compression losses, because CBM gas is produced at low pressure (few bars).	efficiency separation process	proven					
CO2 compression	standard tech	New compressors can be build at compression station or at well site depending on economics	integrated design compression site and well site meeting injection specs.	proven					
M&V operational									
Well	Standard Sensors	Risk of leakage of CO2 comparable or smaller than risk of methane leakage. Monitoring similar as CBM, but include CO2 sensors. Also, there is standard mining technology to monitor methane and CO2 in mines.	detect leakage both concentration and flux	proven					
Surface	Standard Sensors	In CBM field migration of methane to surface always poses a risk when de-watering. CO2 leakage is less likely because it adsorbs stronger to the coal. Monitoring program in conjunction with existing methane monitoring program.	detect leakage both concentration and flux	proven					

Scope of technology blocks for storage – ECBM (4/4)

Technology Block function	Technology	Scope	Capacity and Performance (specification parameters)	Proven	Expected proven by 2012	Expected for Flagship Demo (minimum perform)	Tools	Commercial	Work flow
Ground water	Standard Sensors	Again risk of methane contamination due to CBM operation is higher, comparable monitoring techniques for CO_2	detect CO_2 or CH_4 contamination of water	proven					
Closure methodology									
Facilities	Standard abandonment CBM	Re-use of facilities (compressors etc.) recommended		proven					
wells	Standard abandonment CBM	RECOPOL showed that it is difficult to get CO_2 out of the coal		proven					
CO_2 containment M&V	Standard monitoring techniques	Risk CH_4 leakage due to CBM at well site larger than CO_2 leakage.		proven					
Post Closure M&V									
CO_2 containment M&V	sensors surface and water	Similar to post monitoring mining areas (CH_4 leakage)		proven					
Termination procedure									
Relinquishment	legal	Mining rights: Coal needs to be classified as storage medium to avoid conflict with future mining	legal issues need to be resolved						