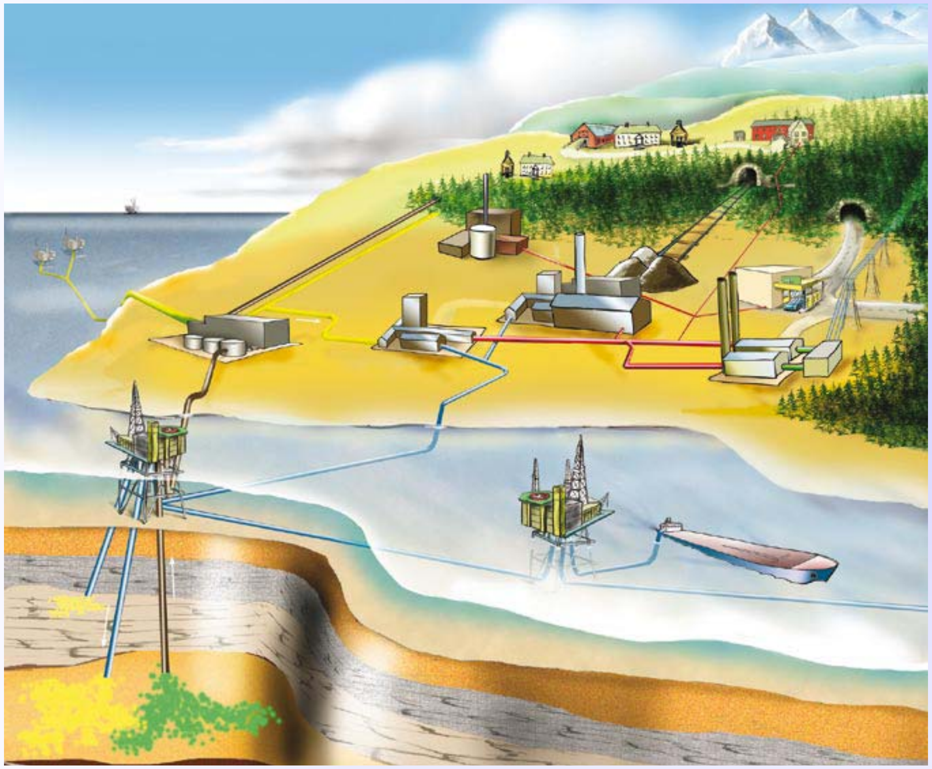

Dynamis - Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage

Petter E. Røkke, SINTEF Energy Research
SP-leader in Dynamis

Acknowledgments to Charles Eickhoff, Progressive Energy Ltd, SP5 leader

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Overview of Dynamis Presentation

- Structure and phases of Dynamis
- Technical component choices: Coal / Lignite / Gas
- Definitions of H_2 and CO_2 purity – why important
- Case Studies – commercial sponsors
  - Storage infrastructure and reservoir assessment
  - Hydrogen prospects
  - EIS issues
  - Efficiency gains – Heat cycle integration and DH / industrial heat load
- Societal anchorage
  - Economics and Financing
  - Public Acceptance

Objectives

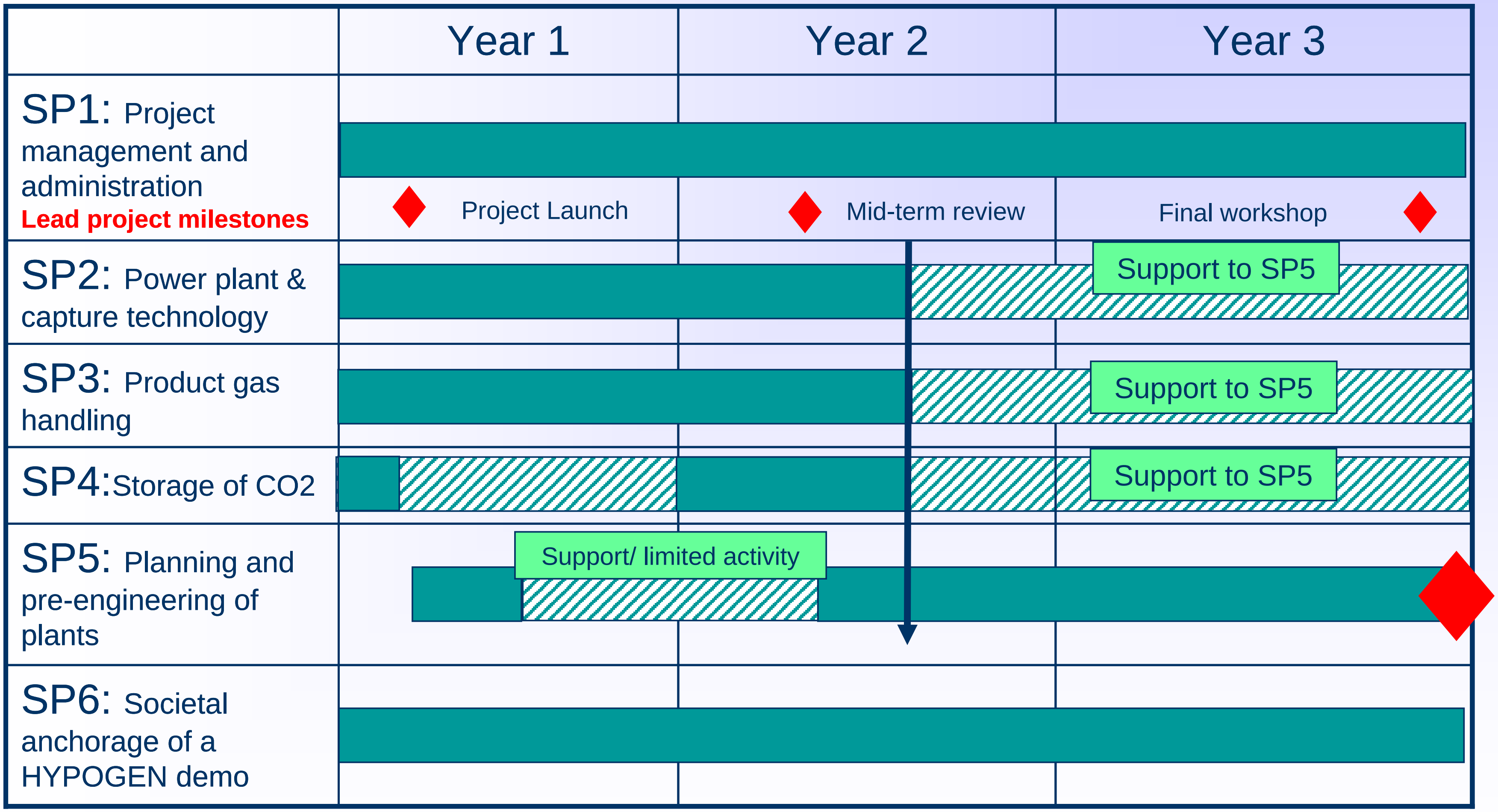
- …prepare the ground for large-scale European facilities producing hydrogen and electricity from fossil fuels with CO_2 capture and permanent safe storage…

- …the scope has been to investigate viable routes to large-scale cost-effective combined electricity and hydrogen production with integrated CO2 management.

Specifications for Dynamis

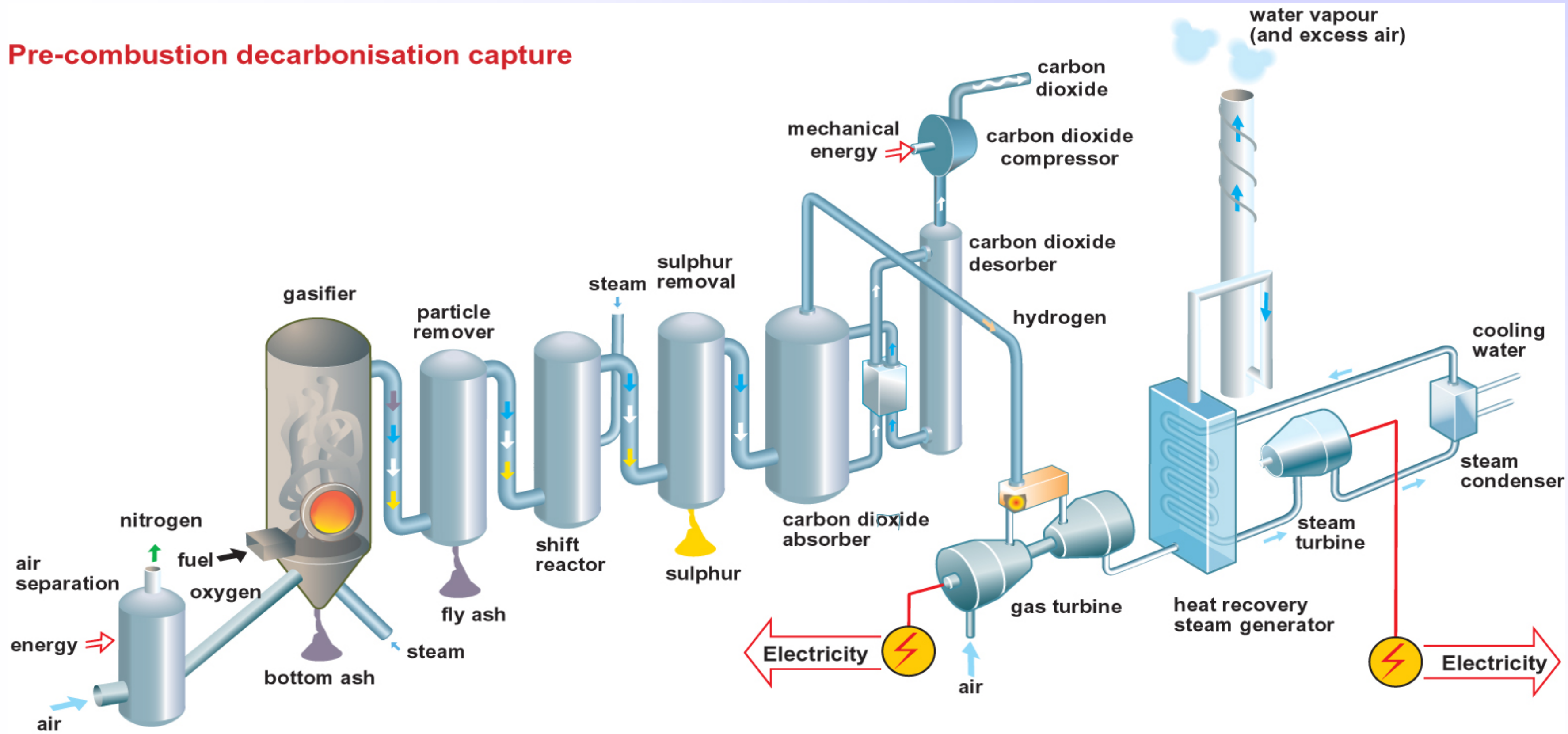
- Power output in the 400 MW class, including in coal cases a hydrogen-fuelled gas turbine
- Hydrogen production corresponding to up to 50 MW higher heating value, and the hydrogen produced fulfilling the specifications of an European hydrogen infrastructure
- 90 per cent CO2 capture rate and
- Significant capture cost reduction from a typical level of €50-60 / ton CO2 at project start 2006

The phases and structure of Dynamis



Technology Choices - Coal

- IGCC Process
  - Evaluation of manufacturers/technologies



Technology Choices – Syngas Turbine

Choice is limited for hydrogen-rich syngas.

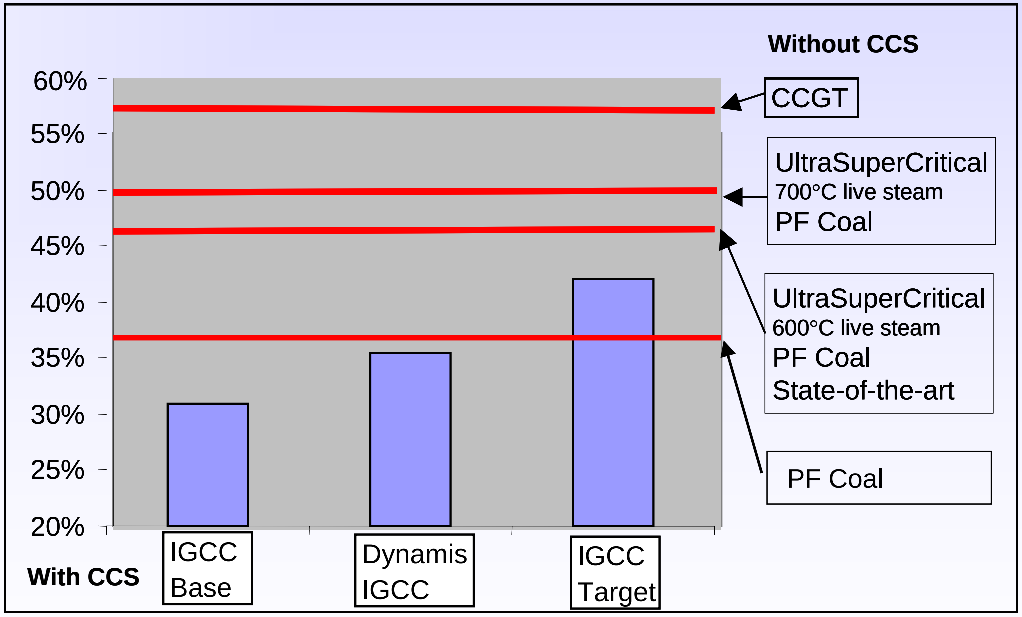
Initial technology choice was E-class GTs for provenness – information provided by project partners.

Case Study sponsors opted for F-class higher efficiency

Machines used:

MHI701F4
GE9FA

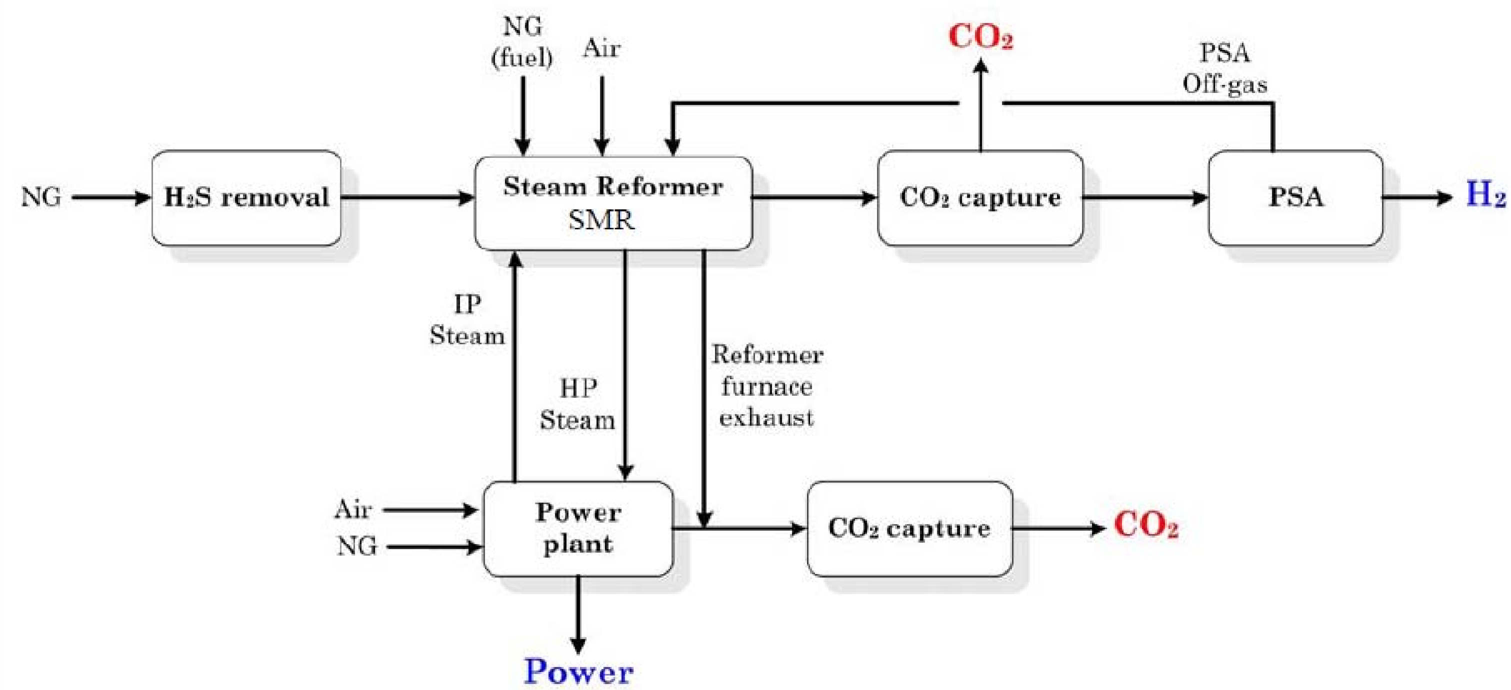
Efficiency Improvement: IGCC with CO_2 Capture



Technology Choices - Gas

Process

- Post-combustion capture and parallel H_2 production most efficient
  - Driven largely by F-class turbine choice on NG



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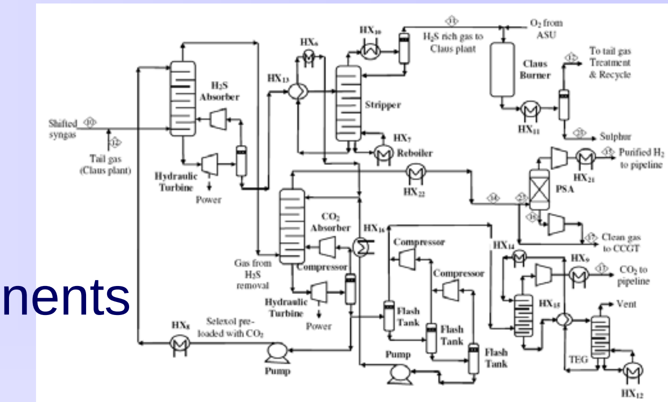
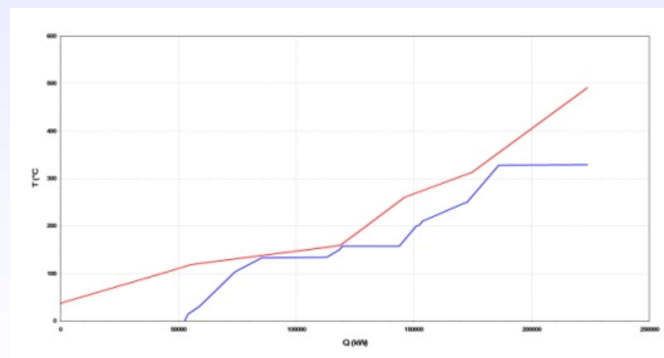
Efficiency Improvements

– 3 basic lines of attack:



- Increase gross efficiency of individual components
  - use of F-class GT
  - careful application of gasifier
- Improve optimisation and hence overall cycle efficiency
  - attention to cycle detail and heat integration
  - use of high- and low-grade heat
- Reduce parasitic load levels
  - attention to ASU (15% of net power)
  - and CO_2 compression (7% of net power)



CO_2 and H_2 Quality Specifications

Specifications determined in order to :

- facilitate European standards in developing networks
- minimise unnecessary quality costs

H_2 specification driven by PEM requirements:

- low levels of cumulative poisons (eg CO, H_2S, NH_3)
- realistic levels of inert contaminants (eg He, Ar, N_2, CO_2)

CO_2 specification extended from ENCAP work and driven by:

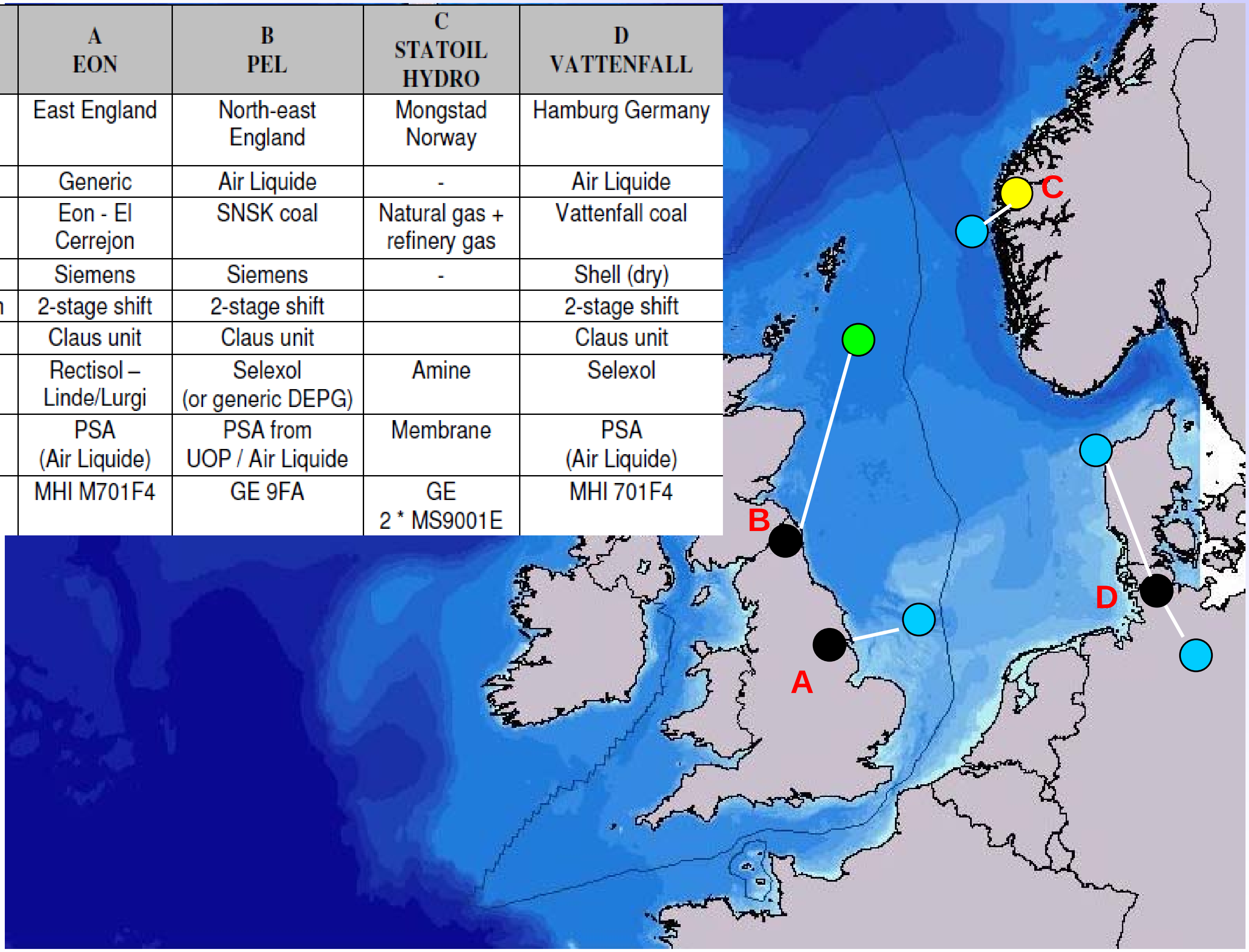
- corrosion and hydrate formation (H_2O)
- safety (eg CO, H_2S CO_2), - combustion / bacteria (O_2)
- miscibility pressure (CH_4, N_2)

Specification published and adopted as preliminary standard

- Reports available at website http://www.dynamis-hypogen.com

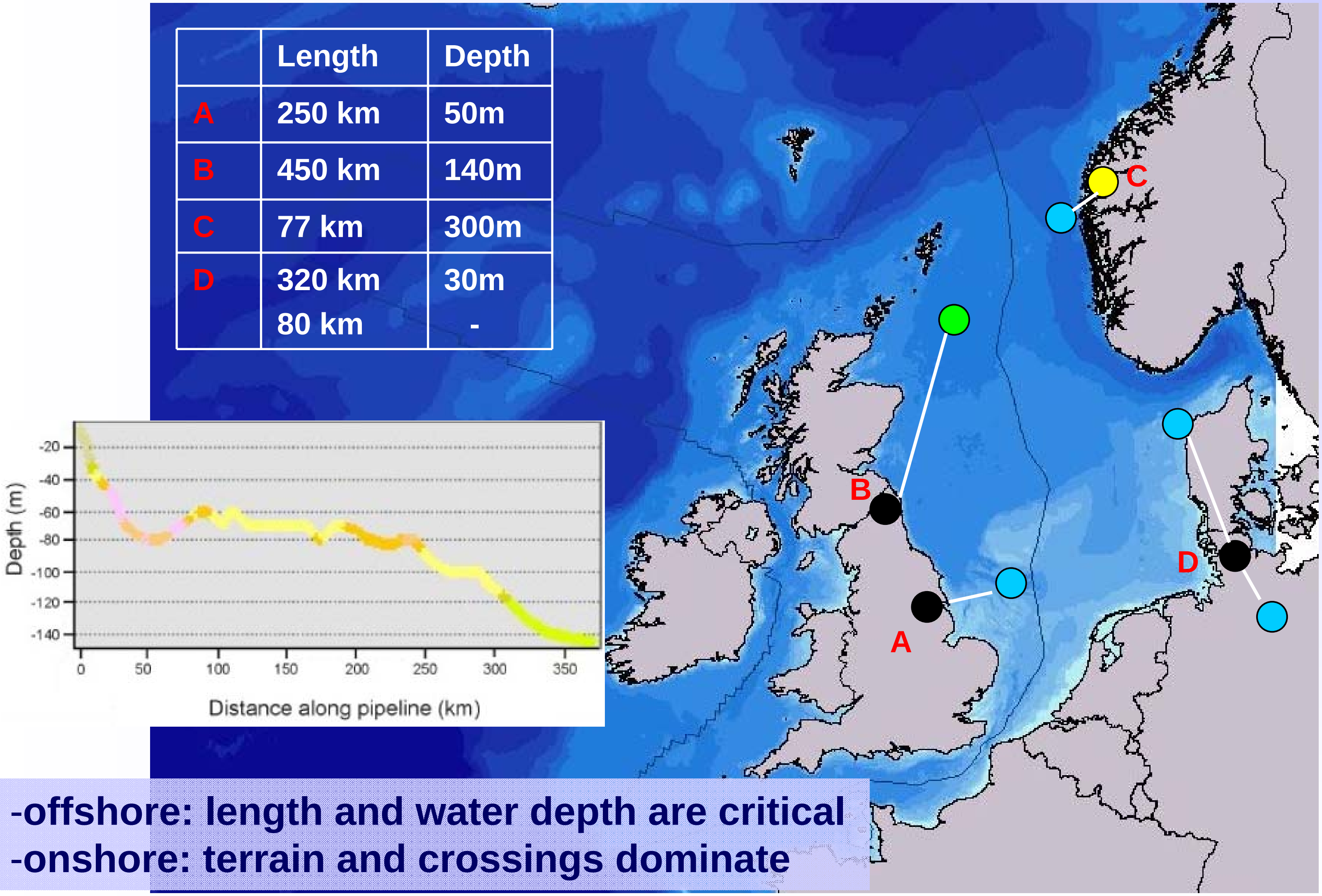
Case Studies: outlines and locations

Case Study	A EON	B PEL	C STATOIL HYDRO	D VATTENFALL
Location	East England	North-east England	Mongstad Norway	Hamburg Germany
ASU	Generic	Air Liquide	-	Air Liquide
Feedstock	Eon - El Cerrejon	SNSK coal	Natural gas + refinery gas	Vattenfall coal
Gasifier	Siemens	Siemens	-	Shell (dry)
Shift / Conversion	2-stage shift	2-stage shift		2-stage shift
Sulphur Removal	Claus unit	Claus unit		Claus unit
Acid Gas Removal	Rectisol – Linde/Lurgi	Selexol (or generic DEPG)	Amine	Selexol
H2 Separation / Production	PSA (Air Liquide)	PSA from UOP / Air Liquide	Membrane	PSA (Air Liquide)
Gas Turbine	MHI M701F4	GE 9FA	GE 2 * MS9001E	MHI 701F4



Case Studies: Pipeline Routing and Costings

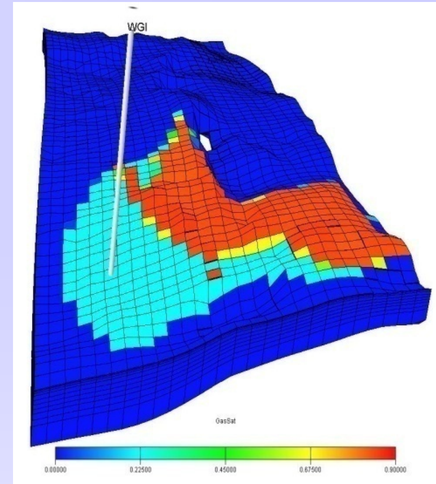
	Length	Depth
A	250 km	50m
B	450 km	140m
C	77 km	300m
D	320 km 80 km	30m -

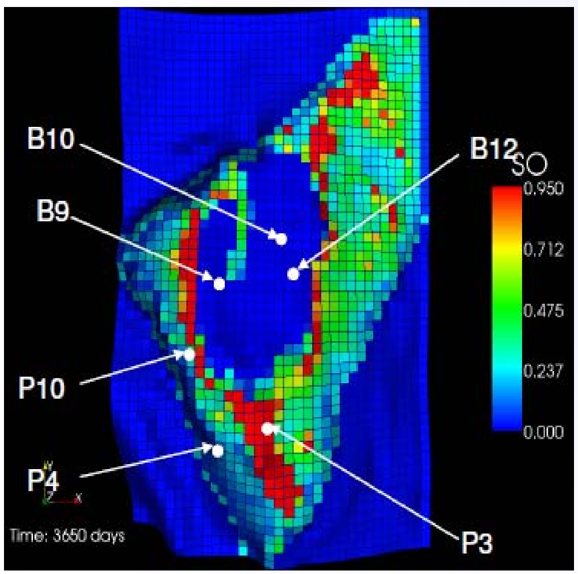


-offshore: length and water depth are critical
-onshore: terrain and crossings dominate

Storage Assessment and Modelling

- Variety of sites assessed with detailed reservoir modelling
- Injection schemes devised to match plant (1.9 – 3.2 Mt/a)
- EOR provides significant benefit and can justify longer transport
- Key issues: overpressure / boundary conditions, geological risk





Case	Location	Type	Structure
A	Southern NS	Aquifer	Anticline
B	Central NS	EOR	Fault block
C	Offshore Mongstad	Aquifer	Tilted
D	Onshore Hamburg	Aquifer	Dome
D	Danish NS	Aquifer	Anticline

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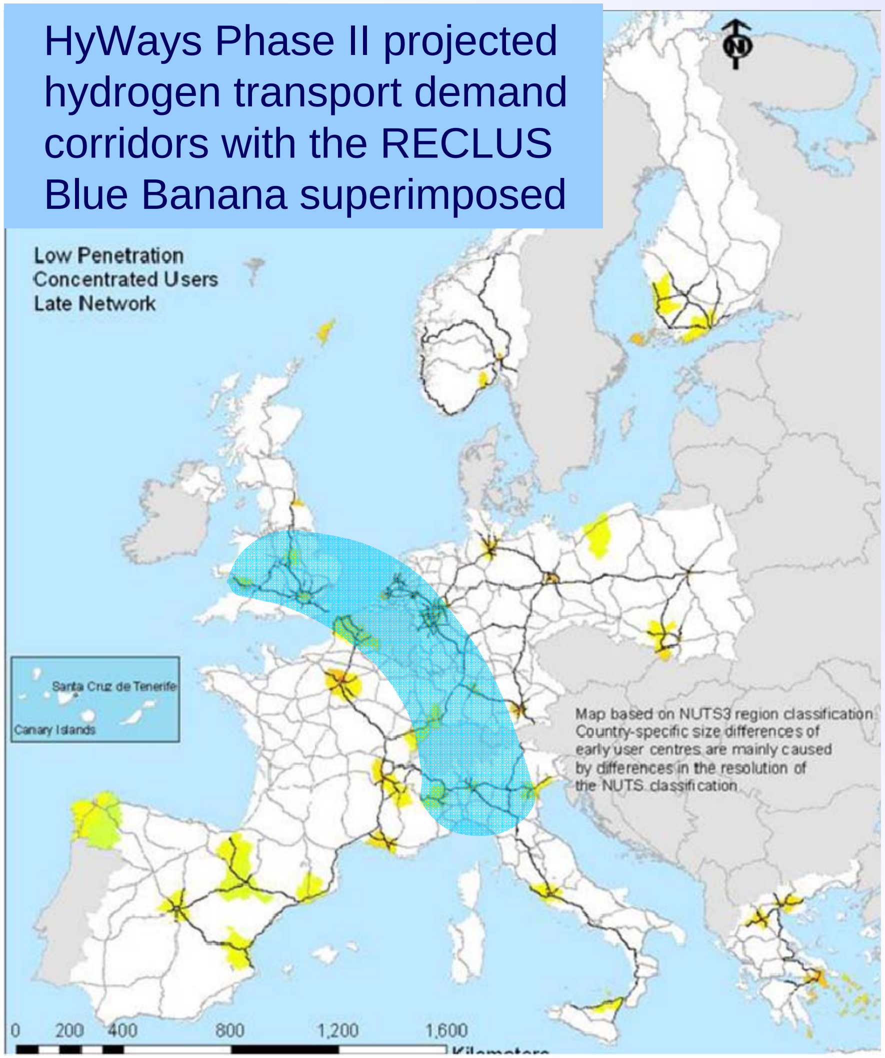
Hydrogen Supply Prospects

HyWays Phase II projected hydrogen transport demand corridors with the RECLUS Blue Banana superimposed



Demand for bulk hydrogen is likely to develop slowly in the transport sector, but good interim industrial demand in key locations.

For the Case Studies:

Hydrogen Demand	**Transport**	**Industry**
East England	Low	Good
N.E. England	Moderate Tyneside	Good
Mongstad Norway	Low	Excellent
Hamburg	Moderate	Moderate

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Specific EIS Issues

EIS topics peculiar to IGCC / CCS:

- Safety case for CO_2 in transport / storage
  - Onshore (proximity) and Offshore
- Impact of marine CO_2 leaks
- Additional water use
- Chemical solvents
- Syngas / CO_2 flaring
- Other impacts similar to regular power stations

CO_2 storage sub-sea issues being addressed (OSPAR, LC);
Cross-border pipelines to be resolved

Plant Key Risks

Key remaining risks in CCS chain:

- High capital cost compared to alternatives
- Immaturity of total technology and lack of performance wraps
- CO_2 storage technical / geological risks
- Immaturity and volatility of ETS Carbon Price
- Novel CCS chain commercial arrangements

Economics and Financeability

Banks and Shareholders will only support with acceptable conditions

Commercial "Gap" has to come from EC / MS on behalf of citizens

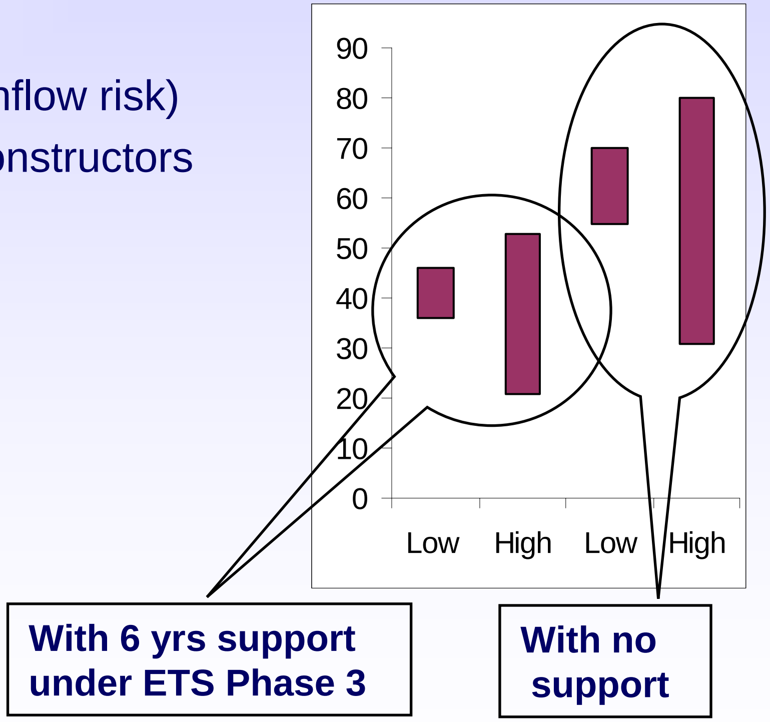
Credit Crunch - credit availability squeeze will heighten requirements

Hence to be financeable, CCS projects need:

- availability guarantees, technology wraps
- contracted revenues including CO_2 (minimise cashflow risk)
- novel risks covered by government / sponsors / constructors

Case Study project financial process:

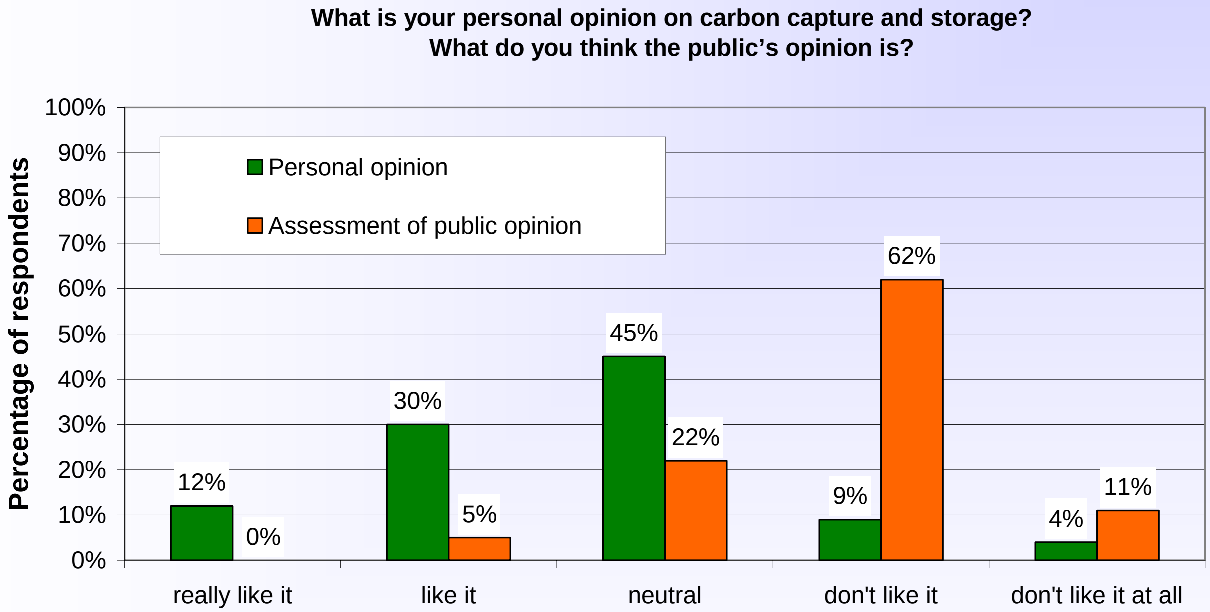
- costing along whole CCS chain,
- financial modelling against scenarios
- evaluation of viability against hurdle rate
- value of carbon price required (fixed floor)
- with and without support mechanism



Professionals' view of acceptance of CCS

Example result from surveying GHGT8 participants 2007:

Professionals are sceptical about public opinion on CCS



Key issues:

- Lack of public information about CCS: outline and risks
- CCS as complementary bridging technology with renewables / nuclear

Consortium - 32 partners from 12 countries

–***Co-ordinator:***

SINTEF Energy Research

–***Partners:***

– ALSTOM (Schweiz) AG
– ALSTOM Power Centrales
– ALSTOM Power Environment ECS France
– BP International Ltd
– Bundesanstalt für Geowissenschaften und Rohstoffe
– E.ON UK plc
– Ecofys b.v.
– ENDESA Generación S.A.
– ENEL Produzione S.p.a.
– Etudes et Productions Schlumberger
– European Commission - DG JRC – Institute for Energy
– Fraunhofer Institute for Systems and Innovation Research
– Geological survey of Denmark and Greenland
– IEA Greenhouse Gas R&D Programme
– Institut Français du Pétrole
– L'AIR LIQUIDE
–Natural Environment Research Council (British Geological Survey)
–Netherlands Organisation for applied Scientific Research (TNO)
–Norsk Hydro ASA
–Norwegian University of Science and Technology
–Progressive Energy Ltd
–SHELL Hydrogen B.V.
–Siemens Aktiengesellschaft
–SINTEF
–SINTEF Energy Research
–SINTEF Petroleumsforskning AS
–Société Générale London Branch
–Statoil
–Store Norske Spitsbergen Kulkompani AS
–Technical University of Sofia
–Vattenfall AB
–Vattenfall Research and Development AB

Final product of Dynamis currently in progress:

A public brochure with main findings from Dynamis and recommendations on further use of the results.

Website: http://www.dynamis-hypogen.com

Thank you for your attention!