Gas-FACTS

Future Advanced Capture Technology Systems

EPSRC
Engineering and Physical Sciences Research Council

UKCCSRC PACT FACILITIES

Dr Karen N Finney
ETII Research Fellow at University of Leeds
Deputy Technical Director of Gas-FACTS

Coal Research Forum: 8th April 2014

Presentation Outline

- Project summary and background
- Work package overview, integration and timescales
- Details and results summary/outputs of WPs so far:
  - **WP1**: gas turbines
  - **WP2**: advanced post combustion capture
  - **WP3**: whole systems performance
  - **WP4**: impact delivery and expert interaction

Project Summary

- Three-year EPSRC-funded programme (FEC of over £3m)
- Five academic institutions involved: universities of Cranfield, Edinburgh, Imperial, Leeds and Sheffield
- Industrial partners and expert panel includes utilities, OEMs, SMEs, consultants and international research partners: SSE, ESBI, Scottish Power, Howden, Doosan Power, Siemens, Sulzer, BG, HATS, Visage Energy, Carnegie Mellon University and cenSE

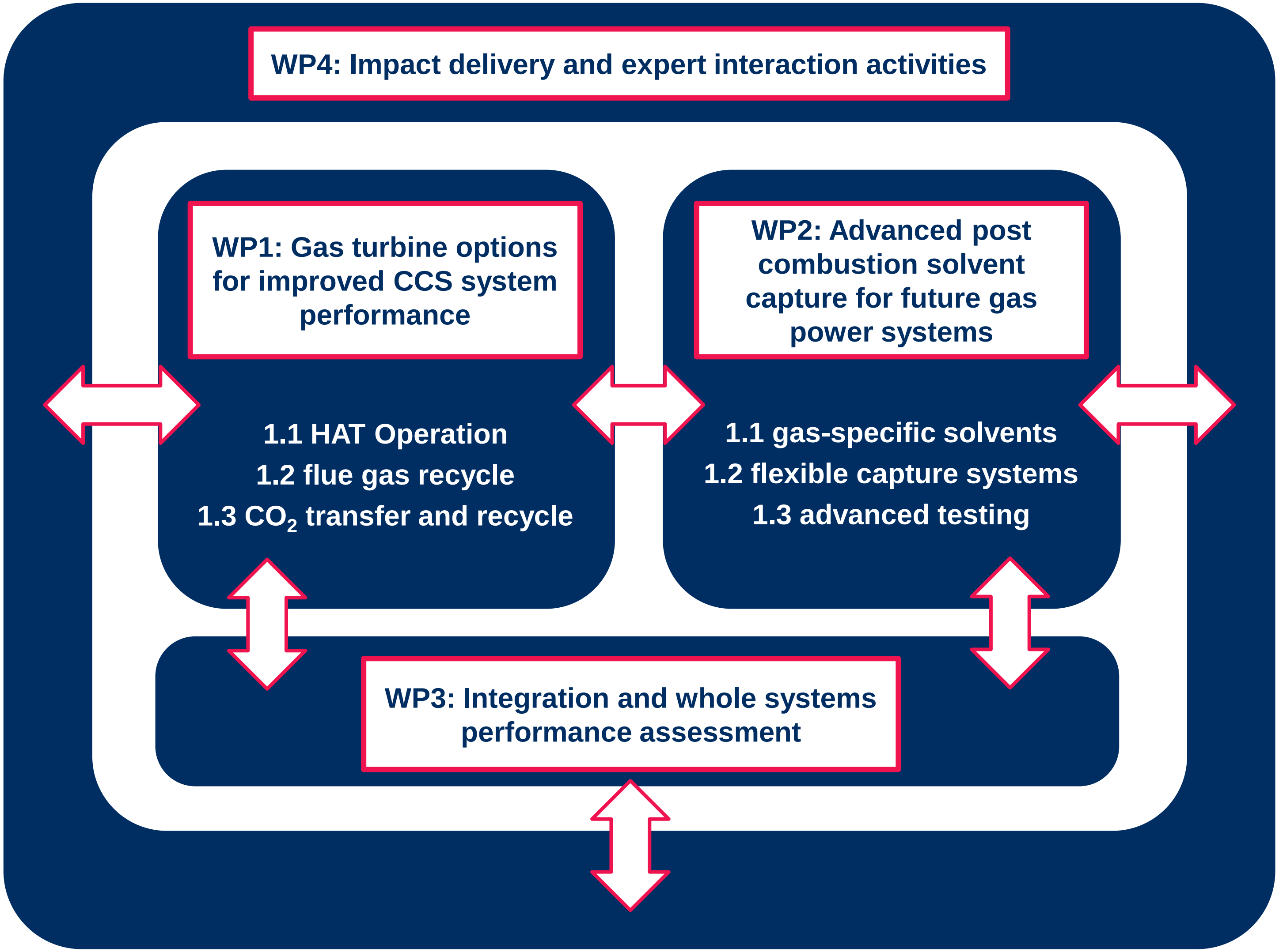
Project Summary

- Key objective: provide important underpinning research for UK CCS development and deployment on CCGT power plants, particularly for gas turbine modifications and advanced post-combustion capture technologies
- Principal candidates for deployment in a possible tens-of-£billions expansion of the CCS sector between 2020 and 2030, and then operation until 2050 or beyond
  - in order to meet UK CO_2 emission targets
- To take the results to impact with industrial, academic, government and other users

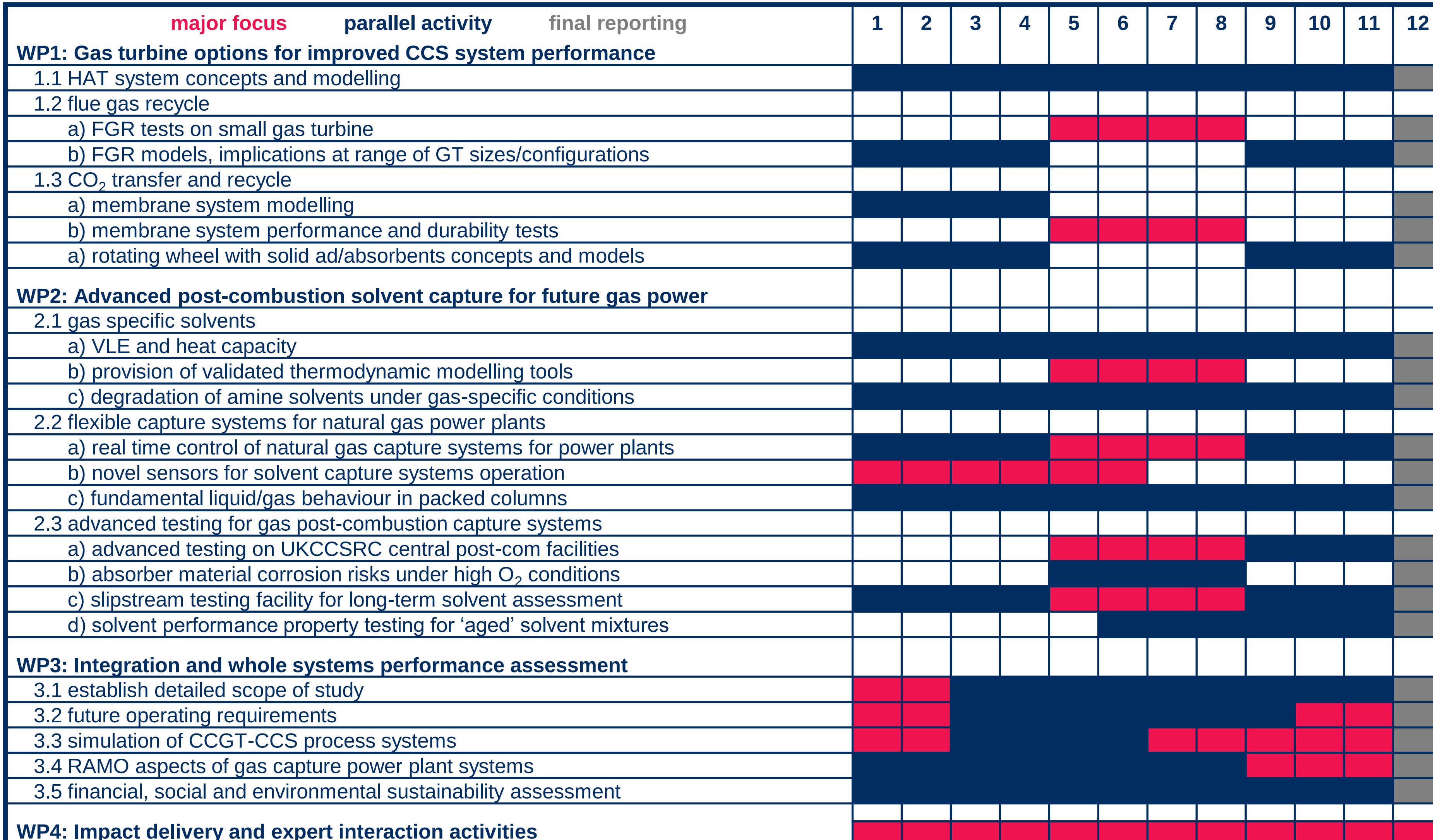
Work Packages

- **WP1:** Gas turbine options for improved CCS system performance
  - **Leeds**/Sheffield/Cranfield/Edinburgh
- **WP2:** Advanced post-combustion solvent capture for future gas power systems
  - Leeds/**Imperial**/Cranfield/Edinburgh
- **WP3:** Integration and whole systems performance assessment
  - Leeds/Imperial/Cranfield/**Edinburgh**/Sheffield
- **WP4:** Impact delivery and expert interaction activities
  - Leeds/Imperial/Cranfield/**Edinburgh**/Sheffield

Work Package Integration



Project Timescales



Work Package 1

Gas turbine options for improved CCS system performance

1.1: HAT system concepts and modelling (Leeds/Sheffield)

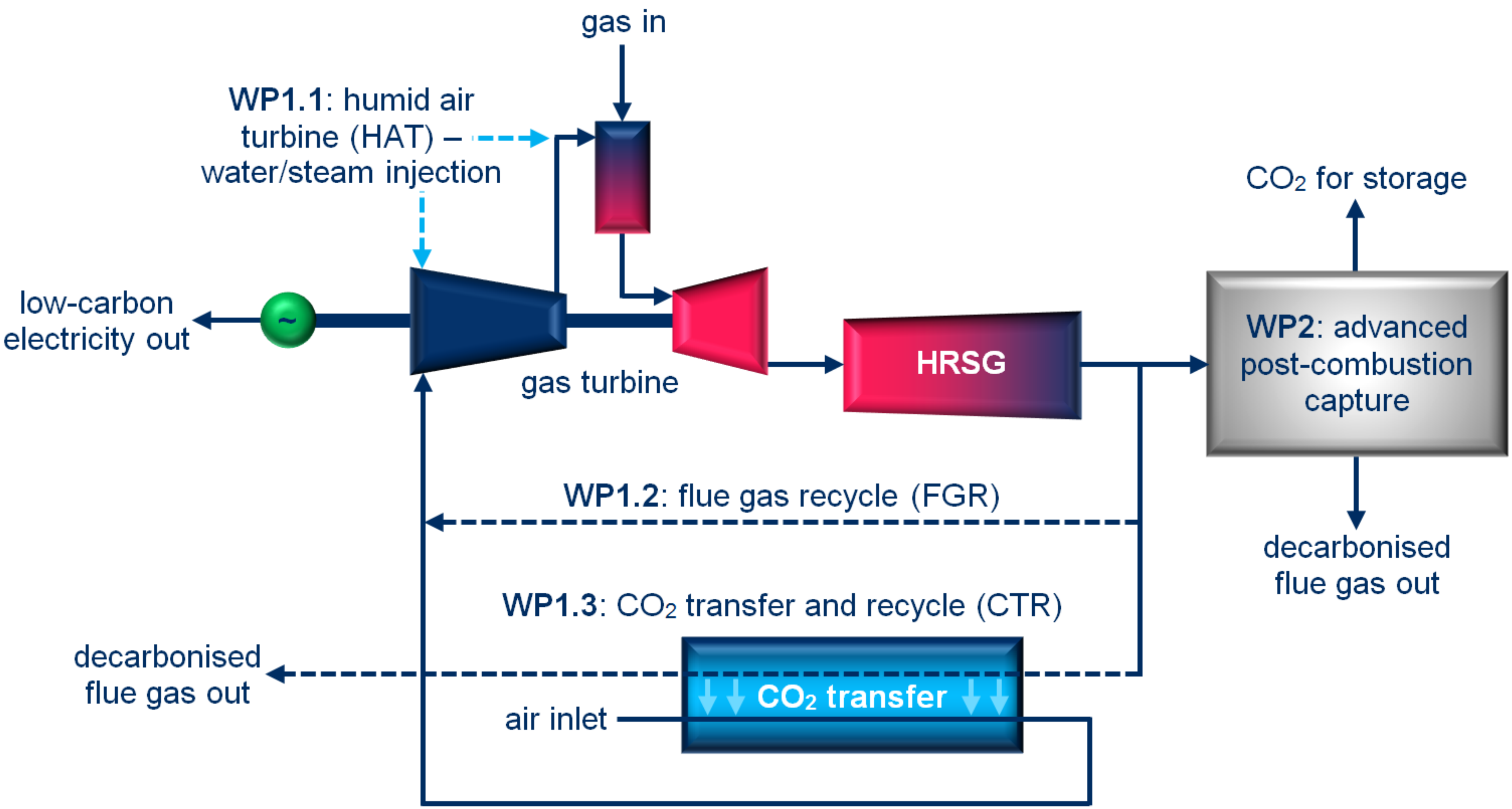
1.2: Flue gas recycle (Leeds/Sheffield/Edinburgh)

- a) FGR tests on small GT
- b) FGR modelling, implications at range of GT sizes/configurations

1.3: CO_2 transfer and recycle (Cranfield/Edinburgh)

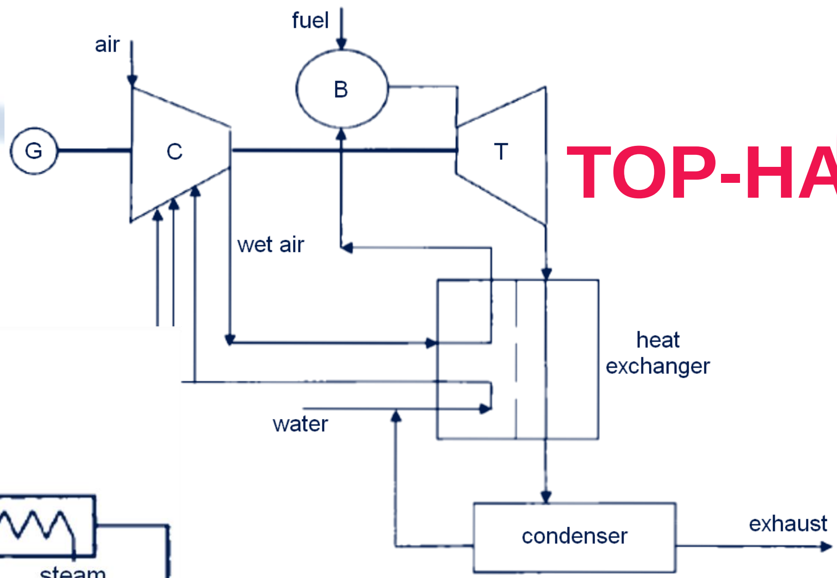
- a) system concepts and modelling
- b) membrane system performance and durability tests
- c) rotating wheel with solid ad/absorbents: concepts and modelling

Work Package Integration



Work Package 1 – Outputs

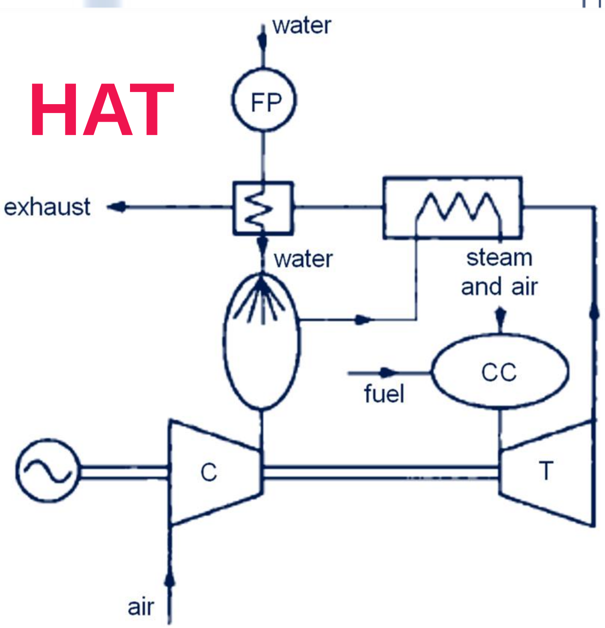
1.1: HAT system concepts and modelling (Leeds)



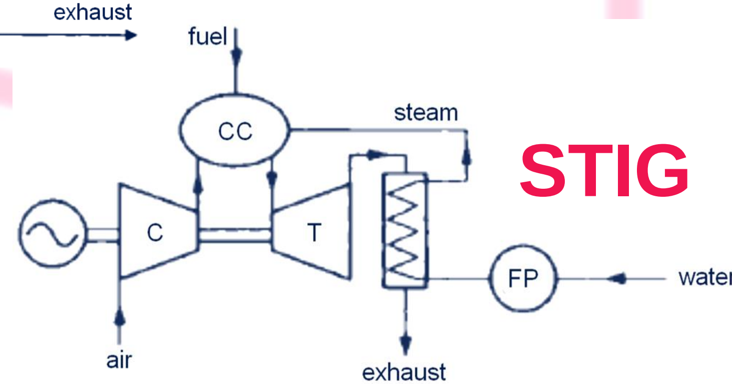
TOP-HAT

Using:
- Aspen Plus®
- Aspen Hysys
- Pro II
- gPROMS
- Ansys

HAT



STIG



Horlock, J.H. (2003) Advanced Gas Turbine Cycles, Elsevier Science Ltd: Oxford, UK

Work Package 1 – Outputs

1.2: Flue gas recycle (Leeds)

a) FGR tests on small GT

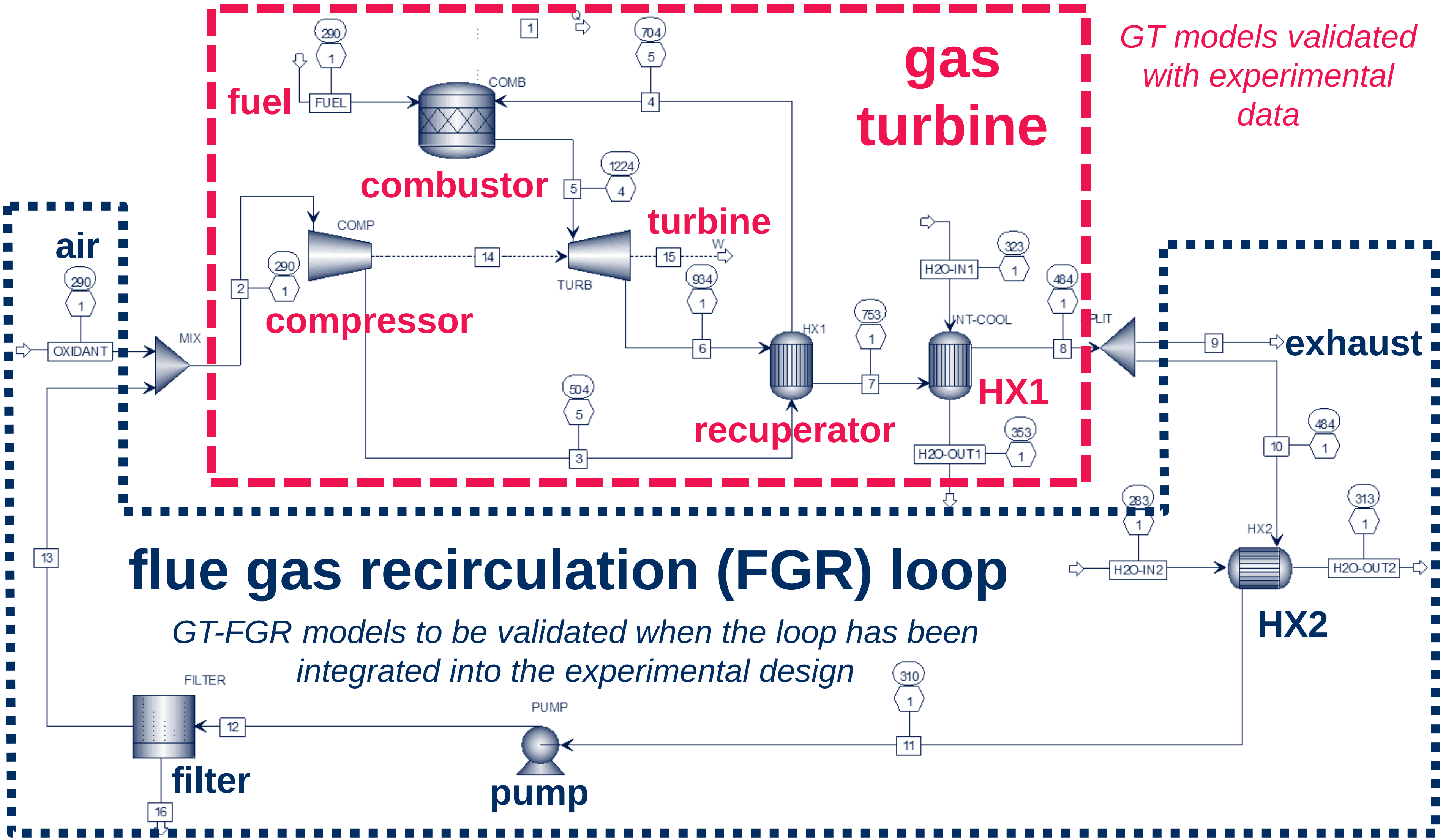
b) FGR modelling, implications at range of GT sizes/configurations

Gathering baseline data at different loads, concerning:

- turbine speed
- turbine inlet and outlet temperatures
- flue gas concentrations of CO_2, O_2, CO, NOx, SOx, unburned hydrocarbon speciation, particulate emissions, etc.

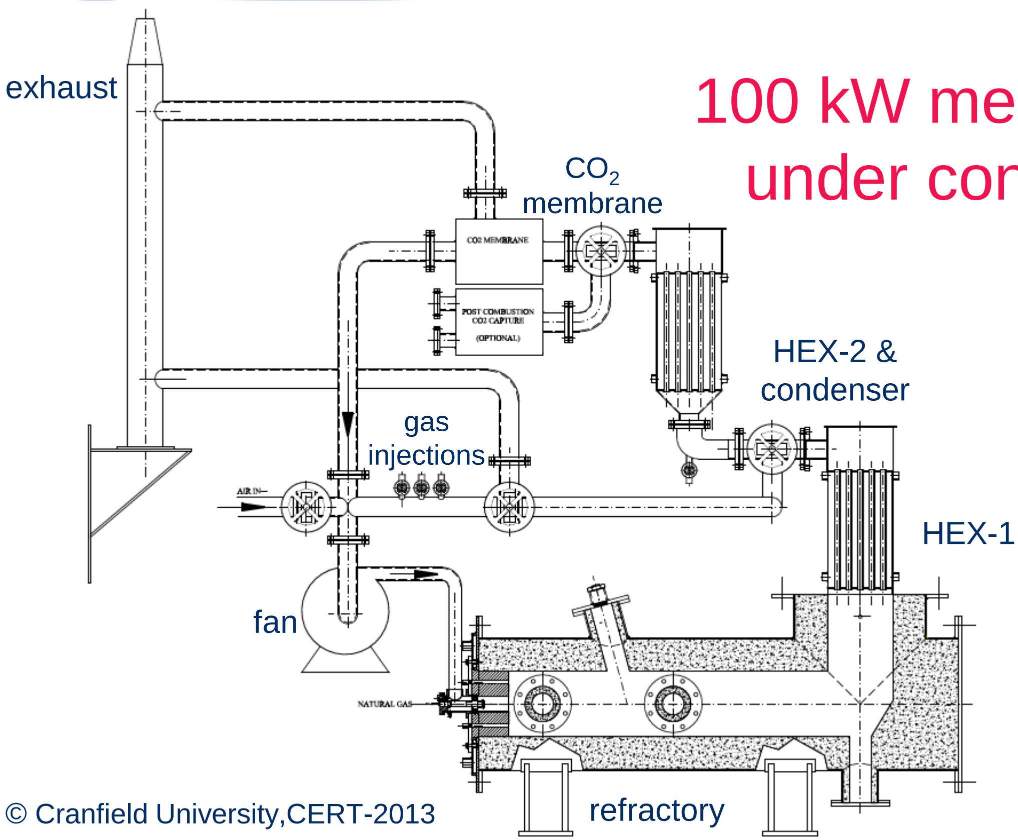
Instrumentation of the turbine for additional temperature, pressure and flowrate measurements

Work Package 1 – Outputs

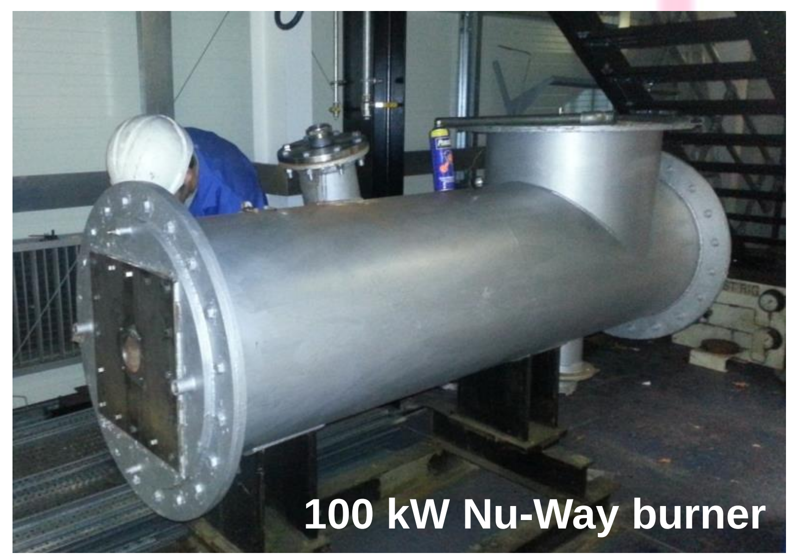


Work Package 1 – Outputs

1.3b: CO_2 transfer and recycle (Cranfield) – membrane system performance and durability



100 kW membrane rig under construction



100 kW Nu-Way burner

Work Package 2

Advanced post combustion solvent capture for future gas power systems

2.1: Gas-specific solvents (Leeds/Imperial)

a) new thermodynamic data for gas-specific solvents/operating conditions, specifically for VLE and heat capacity

b) provision of validated thermodynamic modelling tools capable of predicting the necessary equilibria and other physical properties, such as enthalpy changes and viscosity, that affect the process

c) provision of new chemical data and predictive models pertaining to oxidative and thermal degradation of amine solvents under gas-specific operating conditions

Work Package 2

Advanced post combustion solvent capture for future gas power systems

2.2: Flexible capture systems for natural gas power plants (Imperial/Edinburgh)

a) real time control of natural gas capture systems for power plants

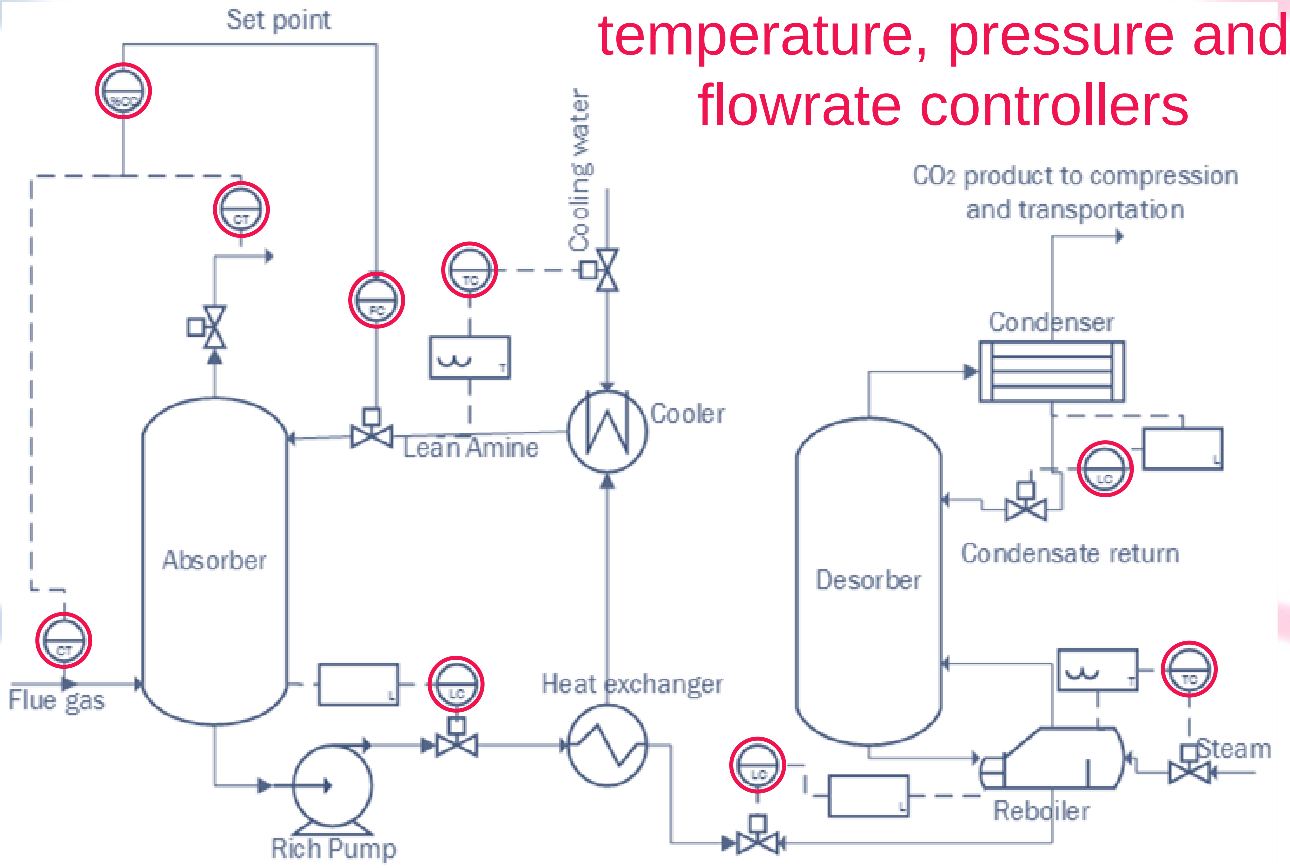
b) novel sensors for solvent system operation under gas-specific conditions

c) fundamental liquid and gas behaviour in packed columns under steady state and dynamic operation

Work Package 2 – Outputs

2.2a: Flexible capture systems for natural gas power plants (Imperial) – real time control

temperature, pressure and flowrate controllers



Work Package 2 – Outputs

2.2b: Flexible capture systems for natural gas power plants (Edinburgh) – novel sensors

Objectives of COMCAT PhD project

- Develop an instrumentation setup to characterize capture solvents quickly, cheaply and online
- Build a prototype sensor and deploy it at industrial capture sites for process measurements
- Integrate the sensor into plant control systems to enable more effective and faster responding process control
- Investigate the effects of real world factors on the characterisation method (degradation products, heat stable salts, particulates, etc.)

Work Package 2 – Outputs

2.2c: Flexible capture systems for natural gas power plants (Edinburgh) – fundamental liquid/gas behaviour

Methodology:

- semi-analytical approach: base state, linear stability and energy analysis

What has been accomplished so far:

- full linear stability analysis for liquid interface for a wide range of system parameters
- parallelized solver for high resolution 3D direct numerical simulations
- numerical results validated against linear theory
- ability to study interaction between several physical processes (fluid dynamics, mass/heat transfer, etc.) in great detail

Work Package 2

Advanced post combustion solvent capture for future gas power systems

2.3: Advanced testing for gas post-combustion capture systems (Imperial/Cranfield/Edinburgh)

a) advanced testing on UKCCSRC central post-combustion facilities

b) absorber material corrosion risks under high O_2 conditions (specific to gas)

c) slipstream testing facility for long term solvent assessment on natural gas power plants

d) solvent performance property testing for ‘aged’ solvent mixtures

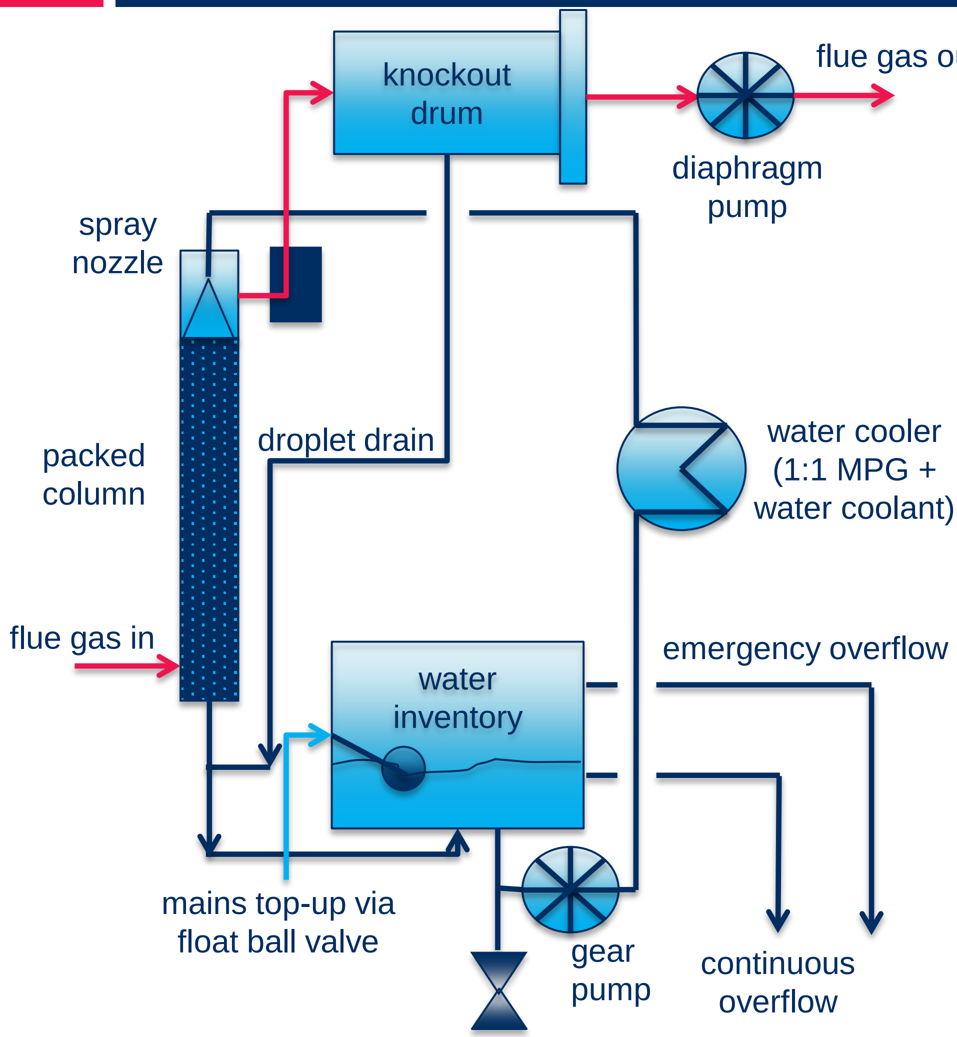
Work Package 2 – Outputs

2.3c: Advanced testing for gas post-combustion capture systems (Edinburgh) – slipstream testing facility

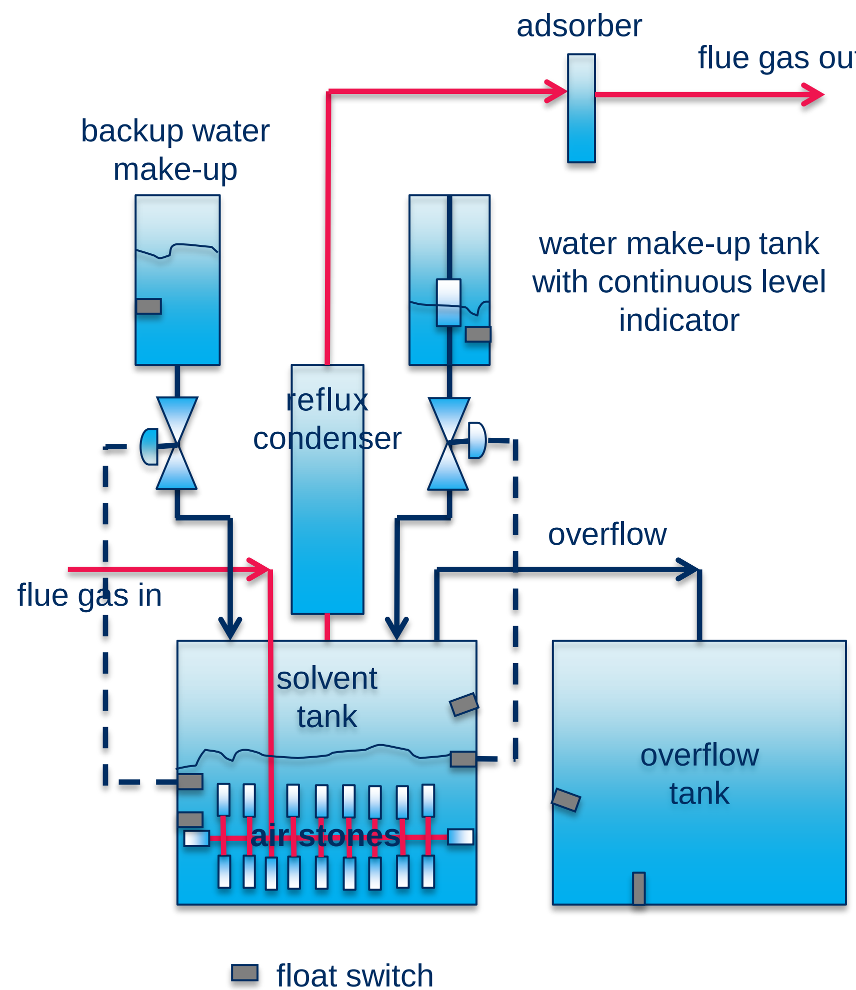
FEATURES

- **Flow rates**: ~1 l/min mains water and ~10 l/min of flue gas
- **Liquid inventory**: 20 litres of solvent, 10 litres of 50% propylene glycol in water, 20 litres mains water, 15 litres deionised water
- **Inlet gas conditioning**: direct contact cooler and knockout drum
- **Outlet gas conditioning**: condenser and activated carbon adsorption filter
- **Analysis**: O_2/CO_2 monitoring on inlet and outlet gas lines (ammonia sensor to be retrofitted on outlet)
- **Measurement**: temperature, flow, level and pressure at key points within the system to log experimental conditions and enable remote fault identification
- **Safety**: fire alarms system, automatic fire extinguishers, low pressure relief ensures that no equipment in the unit is classified as a pressure system

Work Package 2 – Outputs



inlet gas conditioning system



solvent tank/outlet gas conditioning

Work Package 2 – Outputs

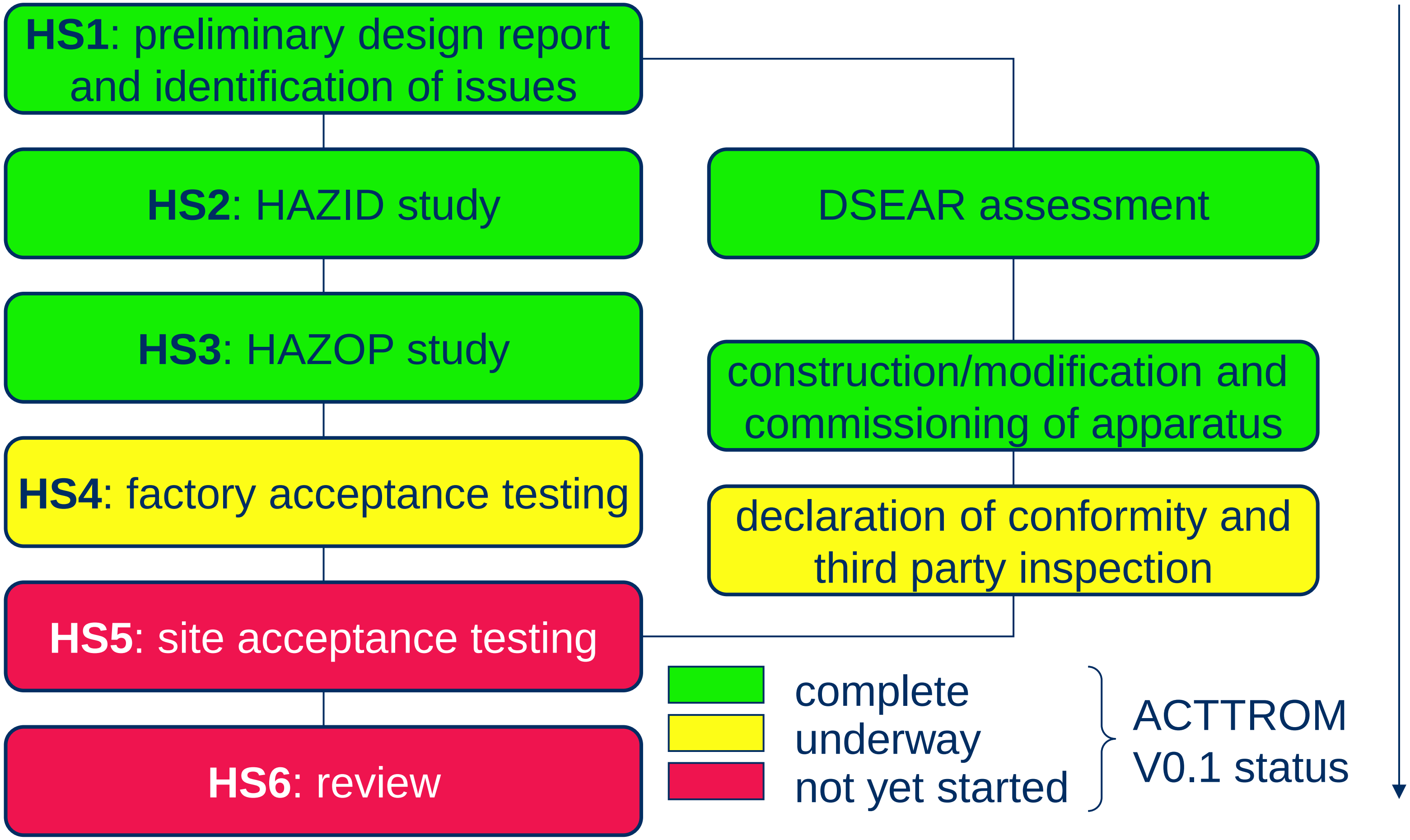
Solvent tank, outlet gas conditioning/analysis and water makeup tanks

Control systems and fluid chilling units

Inlet gas conditioning

Work Package 2 – Outputs

ABB six-stage Hazard Study process **Parallel Processes**



Process must be repeated for every major modification or integration of new apparatus

Work Package 3

Integration and whole systems performance assessment

3.1: Establish the detailed scope of the study (Edinburgh as academic coordinator)

3.2: Future operating requirements (Edinburgh)

3.3: Simulation of CCGT-CCS process systems with simultaneous trade-offs between solvent and GT configurations under realistic constraints (Edinburgh/all)

3.4: RAMO (reliability, availability, maintainability and operability) aspects of gas capture power plant systems (Edinburgh)

3.5: Financial, social and environmental sustainability assessment of Gas-FACTS advanced capture systems (Edinburgh)

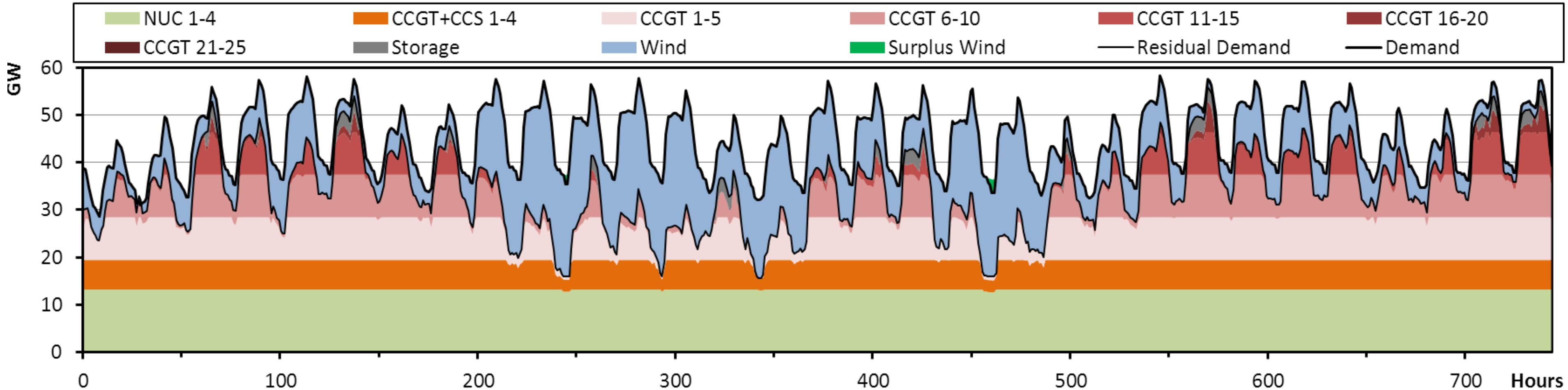
Work Package 3 – Outputs

3.2: Future operating requirements (Edinburgh)

Objective of EURECA PhD project:

- investigate the operating regimes of conventional power plants in illustrative future scenarios with large contributions from wind and electricity storage capacity
- wind speeds from a high-resolution atmospheric mesoscale wind resource model, transformed to power outputs using multi-turbine aggregate power curves
- economic dispatch unit commitment model integrated with a Monte Carlo based optimisation model of energy storage
- preliminary scenarios investigating the required performance characteristics such as part-load efficiency, ramp rates, start-up times and shutdown times

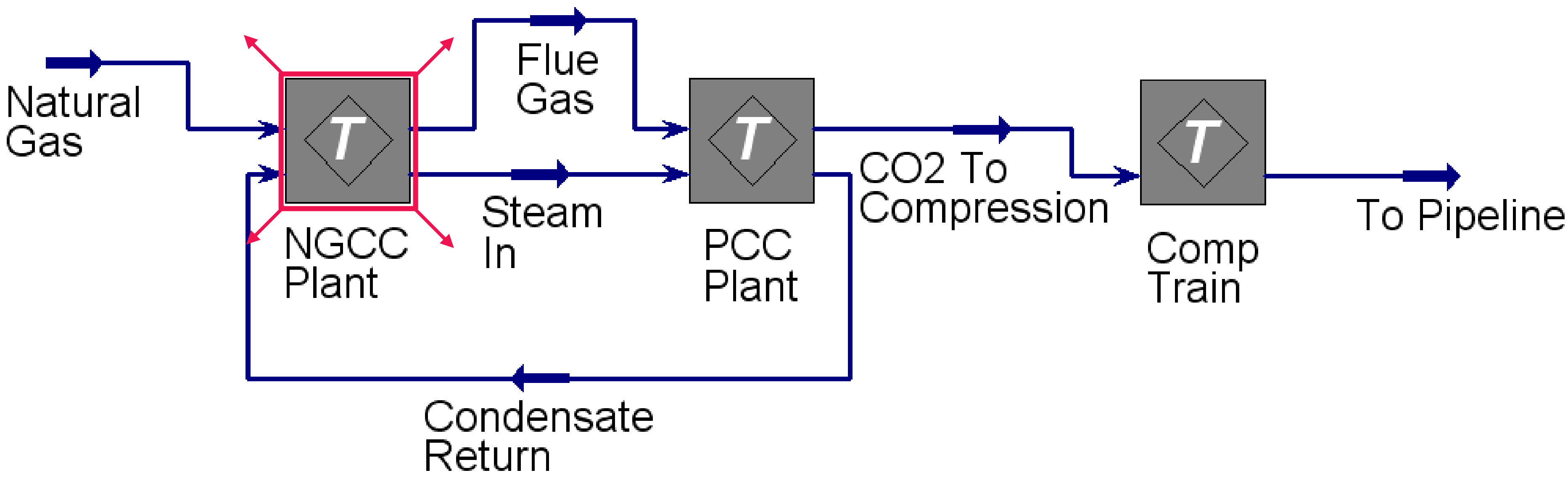
Work Package 3 – Outputs



- Illustrative generation dispatch pattern in Great Britain with January 2006 weather and demand at hourly temporal frequency
- Generation portfolio consists of 4 Nuclear 3300 MW_e, 4 CCGT+CCS 1560 MW_e, 25 CCGT 1800 MW_e, wind 30 GW and energy storage 3 GW with round-trip efficiency 80%
- CO_2 emission factor for natural gas assumed to be 0.22674 $tCO_{2\text{-eq}}$ per MWh_{th} and carbon costs £30/tCO_2
- CCGT+CCS marginal costs are artificially lowered/subsidised by £30/MWh_e to adjust merit-order position

Work Package 3 – Outputs

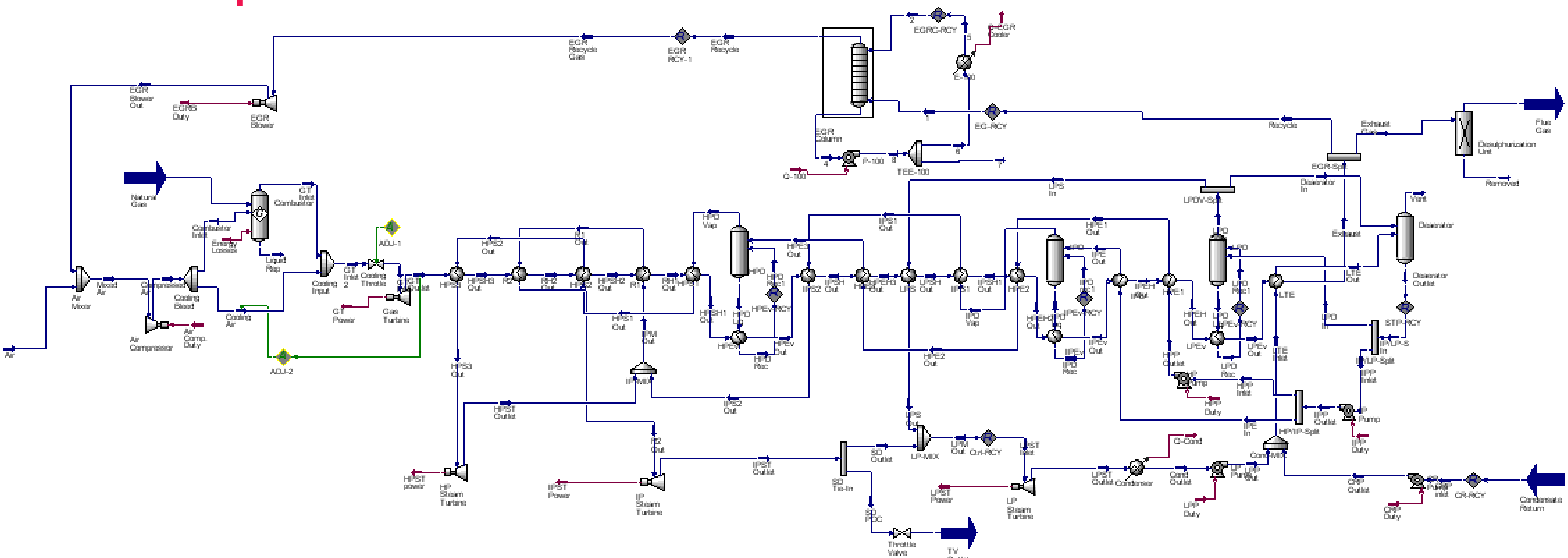
3.3: Simulation of CCGT-CCS process systems with simultaneous trade-offs between solvent and GT configurations under realistic constraints (Cranfield)



Work Package 3 – Outputs

3.3: Simulation of CCGT-CCS process systems with simultaneous trade-offs between solvent and GT configurations under realistic constraints (Cranfield)

NGCC plant model with FGR



Work Package 3 – Outputs

3.3: Simulation of CCGT-CCS process systems (Cranfield)

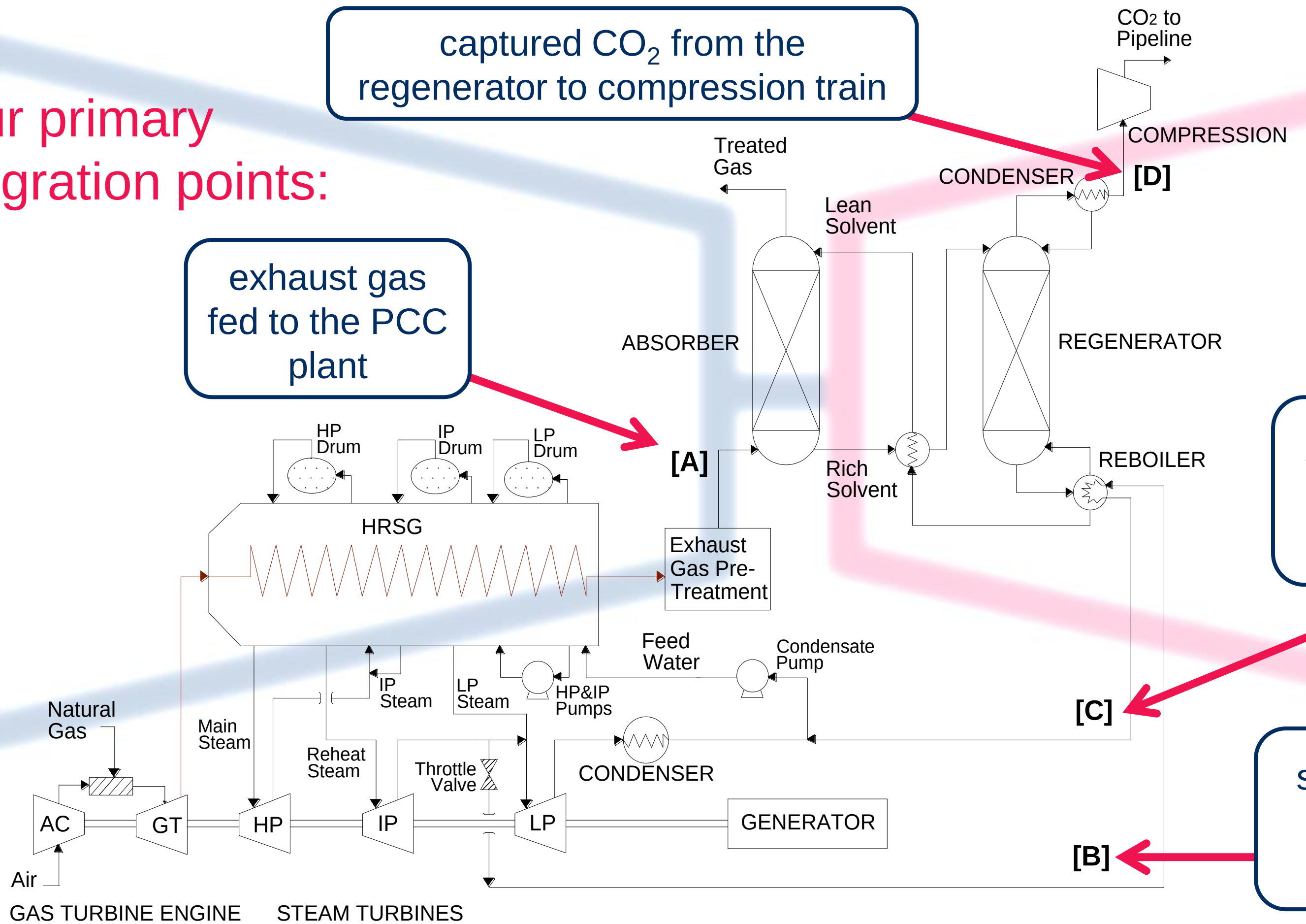
Four primary integration points:

captured CO_2 from the regenerator to compression train

exhaust gas fed to the PCC plant

condensate returned to NGCC plant from the reboiler

steam extracted from IP/LP crossover to regenerate solvent



Work Package 4

WP4: Impact delivery and expert interaction activities

- Establish an ‘Experts Group’ including representatives of the UK and global academic CCS community, UK policymakers, UK Regulators, NGOs, power utilities, original equipment manufacturers and SMEs
- Prepare an ‘Impact Handbook’ combining impact tables with state-of-the-art surveys to ensure pathways to impact pursued by Gas-FACTS researchers are co-ordinated with other significant activities, including excellent science and stakeholder plans, to maximise their effectiveness
- Undertake a sustained programme of engagement activities to impact, including 6-monthly project meetings with Experts Group attendance and workshops, annual meeting/associated summary reports, meetings on topical issues/results, web-based dissemination and other documents (reports, government inquiry responses, papers, articles, etc.)

Work Package 4 – Outputs

Journal papers

- Review papers:
  - Carbon capture from natural gas: Review of the current status and future progress of technologies (*Finney, et al., in progress)*

- Experimental and process simulation papers:
  - Biliyok, C. and Yeung, H. (2013) Evaluation of natural gas combined cycle power plant for post-combustion CO_2 capture integration, *International Journal of Greenhouse Gas Control* 19, 396-405
  - Improving post-combustion carbon capture from natural gas through experimentation and modelling of flue gas recirculation (*Finney, et al., in progress)*
  - A new control strategy for the dynamic performance of a gas fired power plant fitted with CCS *(Mechleri, et al., in progress)*

Work Package 4 – Outputs

Conference abstracts and papers

- 2nd Post Combustion Capture Conference: Selection and development of specific solvents for CO_2 capture from natural gas power systems: monophasic and biphasic *(Zhang, et al.)*
- 23rd European Symposium on Computer Aided Process Engineering: Techno-economic analysis of a natural gas combined cycle power plant with CO_2 capture *(Biliyok, et al.)*
- 24th European Symposium on Computer Aided Process Engineering: Simulation and control of post-combustion CO_2 capture with MEA in a gas fired power plant *(Mechleri, et al.)*
- GHGT-12 (presentations tbc):
  - Experimental and process modelling study of integration of a microturbine with an amine plant *(Agbonghae, et al.)*
  - Experimental impact of CO_2-enriched combustion air on micro-gas turbine and capture performance *(Best, et al.)*
  - Micro gas turbine model with carbon dioxide enrichment *(Ali, et al.)*

Future Advanced Capture Technology Systems

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k.n.finney@leeds.ac.uk

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THANK YOU!

Dr Karen N Finney
ETII Research Fellow at University of Leeds
Deputy Technical Director of Gas-FACTS

k.n.finney@leeds.ac.uk