



EXHAUST GAS RECIRCULATION ON GAS- TURBINE ENGINE

This case study focuses on modelling Exhaust Gas Recirculation (EGR) using Flownex to design and evaluate both application-based and surrogate systems for a 3.5MWe gas turbine, enabling carbon capture feasibility and system optimization.



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CHALLENGE:

The research team needed to understand whether exhaust gas recirculation (EGR) could be applied to an existing 3.5 MWe Solar Turbines Centaur 40 gas turbine to increase exhaust CO₂ concentration and improve the feasibility of pairing the engine with carbon capture equipment. However, implementing a true EGR system requires large cooling loads, dedicated infrastructure, and significant power input. Before committing to a full-scale installation, the team needed a way to evaluate system practicality, determine component sizing, and assess pressure, temperature, and flow behaviour throughout the system. To support experimental planning, they also needed to assess a surrogate EGR concept that uses bottled CO₂ and N₂ to imitate EGR conditions without handling real exhaust gases.

BENEFITS:

Flownex enabled rapid construction of the full gas-handling process, including recirculation loops, cooling systems, surrogate gas distribution, and mixing arrangements, allowing the team to analyse pressure, composition, flow distribution, temperature changes, cooling loads, and component sizing across both proposed systems. The ability to model multiple fluids, predict composition changes, and iterate quickly made it possible to evaluate feasibility and identify constraints before any physical hardware was built.

SOLUTION:

Flownex showed that the application-based EGR system would require an ~8 MW cooling load and a diversion fan to support 50% EGR. The pressure drop of the full system remained well within manufacturer limits.

The surrogate system, which replaces real exhaust with CO₂ and N₂, demonstrated acceptable pressure losses, viable pipe diameters, and full mixing before entering the turbine intake. These results confirmed feasibility for laboratory testing.

Together with complementary CFD mixer studies, the Flownex models helped establish which system could be implemented experimentally and provided essential design inputs for future testing.

INTRODUCTION

Gas turbines produce large volumes of exhaust gas with relatively low CO₂ content, making carbon capture systems large and energy-intensive. EGR offers a practical pathway to increase CO₂ concentration in the exhaust stream and reduce the required size and cost of downstream carbon capture equipment.

The research team working with a 3.5 MWe Solar Turbines Centaur 40 gas turbine needed to understand whether EGR could be practically integrated with this engine and what the associated pressure, mass flow and cooling requirements would be. Because full EGR implementation demands substantial cooling capacity and handling of hot exhaust, the team also investigated a surrogate system, delivering bottled CO₂ and N₂ into the intake, to enable controlled experiments without the infrastructure required for real recirculation.

Flownex was used to build three different models:

1. **An engine model** representing the Centaur 40 to study system-level behaviour under EGR conditions.
2. **An application-based EGR system model** (System A) representing a practical retrofit including cooling, diversion and recirculation components.
3. **A surrogate EGR system model** (System B), based on vaporised bottled gases routed through a distribution system into the turbine intake.

Each model was used to answer different questions and collectively provided the system-level insights needed to guide future laboratory testing.

ENGINE MODEL: ESTABLISHING A BASELINE FOR EGR STUDIES

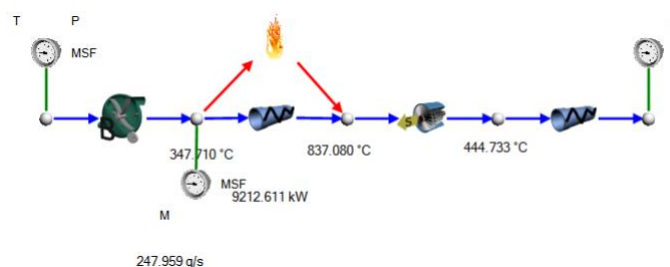


Figure 1: Engine model

Purpose of the Model

The engine model served as a simplified representation of the Centaur 40 for evaluating how exhaust gas recirculation alters exhaust composition and mass flow behaviour at system level. This allowed the team to understand sensitivity to EGR percentages before embedding the engine inside more complex network configurations.

How It Works

The model used basic compressor, combustor, and turbine elements configured with known operational values, pressure ratios, temperatures, and mass flows, set using the Flownex *change design* feature. Combustion chemistry was represented using a CEA adiabatic flame element along with fuel composition data to track how exhaust species change with EGR.

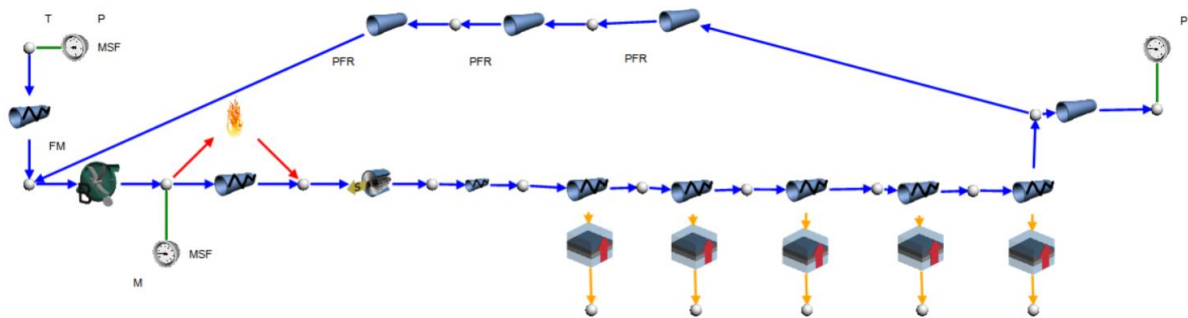


Figure 2: Engine model integrated into an EGR loop

An EGR loop was added to the engine model using non-dimensional flow resistances, a controllable orifice for EGR fraction adjustment, and composite heat exchanger elements to assess exhaust-side cooling requirements.

What the Model Showed

Table 1: Composition results of EGR loop

Component	0% EGR	50% EGR
Carbon dioxide	0.031939	0.056966
Nitrogen	0.759347	0.724823
Nitric Oxide	0.000087475	0.000086614
Nitrogen Dioxide	0.000010021	0
Oxygen	0.18314	0.12113
Water	0.025477	0.096994

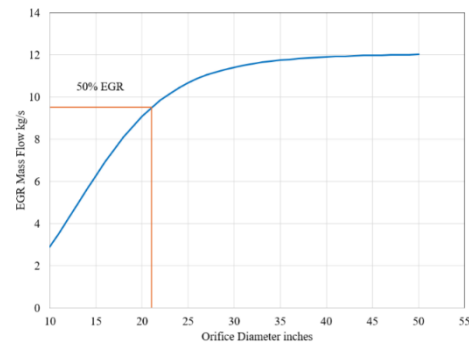


Figure 3: EGR mass flowrate vs orifice diameter

In Table 1 the model demonstrates how exhaust composition shifts when EGR is introduced. At 50% EGR, CO₂ concentration increased noticeably, while O₂ decreased, consistent with expectations and suitable for comparison to future experimental data. In Figure 3 the model also demonstrated that modulating an orifice diameter provides a controllable and predictable means of adjusting EGR mass flow, providing a useful mechanism for future experimental control strategies.

APPLICATION-BASED EGR SYSTEM (SYSTEM A)

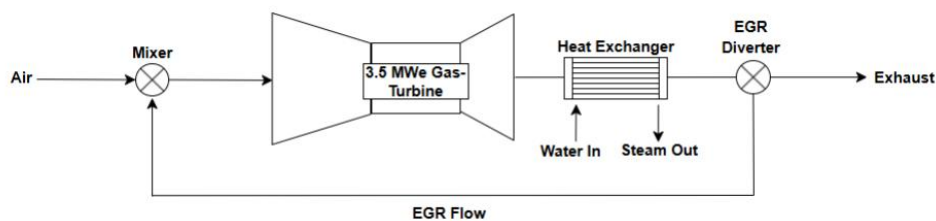


Figure 4: Application-based EGR system (System A)

Why This Model Was Needed

The real EGR concept involves cooling, drying, diverting, and re-introducing a portion of the hot exhaust gas back to the compressor inlet. The team needed to understand:

- Whether the pressure drop of the full recirculation loop stayed within manufacturer limits
- The cooling load and water mass flow required to reduce exhaust temperature
- How geometry choices influence back-pressure
- Whether the system is realistic for experimental implementation at their facility

Since the full EGR system has high thermal and mechanical demands, modelling was essential for feasibility assessment before any hardware decisions.

Model Description

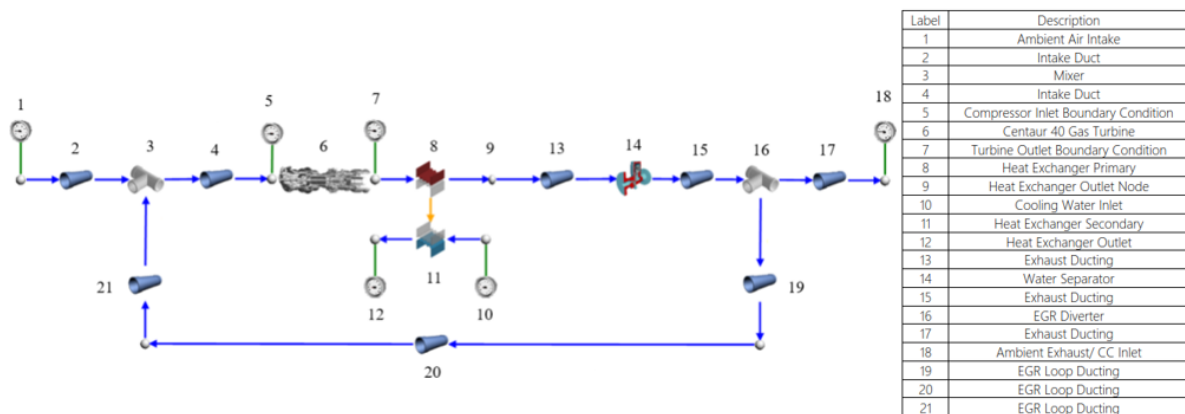


Figure 5: System A model

System A followed the real-world configuration: ambient air enters the intake, mixes with recirculated exhaust, flows to the engine, exits at 445 °C, cools through a heat exchanger, sends condensate to a water separator, and splits between recirculation and onward flow to carbon-capture equipment.

Flownex represented each section using pipes, T-junctions, a primary and secondary heat exchanger, boundary conditions for engine inlet and outlet states, and a pressure-controlled fan to regulate flow to the carbon-capture branch.

Key Findings

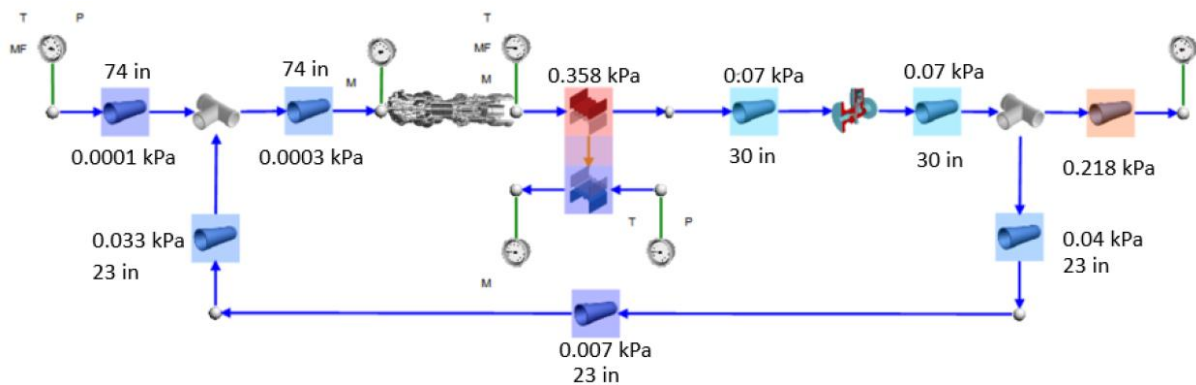


Figure 6: Analyses of the System A model

- **Pressure drop:** The total system pressure loss was 531.97 Pa, well within the allowable 2.48 kPa specified for heat-recovery operation.
- **Cooling requirement:** Cooling exhaust from 445 °C to ~28 °C required ~8 MW of heat removal.
- **Cooling water demand:** Approximately 5–8 kg/s of water was needed depending on modelling assumptions.
- **Condensate formation:** Simulated moisture content confirmed the need for a water dropout component before re-entry to avoid corrosion.

The analysis revealed that the required cooling capacity is beyond what is currently available at the laboratory facility. This finding helped justify exploring the surrogate EGR approach for experimental studies.

SURROGATE EGR SYSTEM (SYSTEM B)

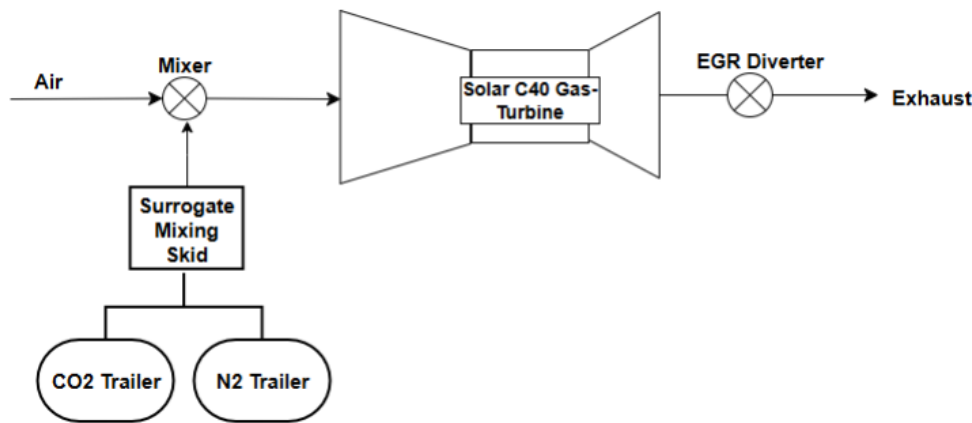


Figure 7: Surrogate EGR system (System B)

Why This Model Was Needed

A surrogate EGR system provides a practical way to study engine behaviour under EGR-like composition conditions without handling high-temperature recirculated exhaust or installing large cooling infrastructure. The goal was to determine whether a pipeline-delivered mixture of vaporised CO₂ and N₂ could achieve the correct mass flow, composition, and mixing characteristics at the compressor inlet.

This model therefore needed to assess pressure loss, required inlet pressures, pipe sizing, and mixing quality through the distribution network.

Model Description

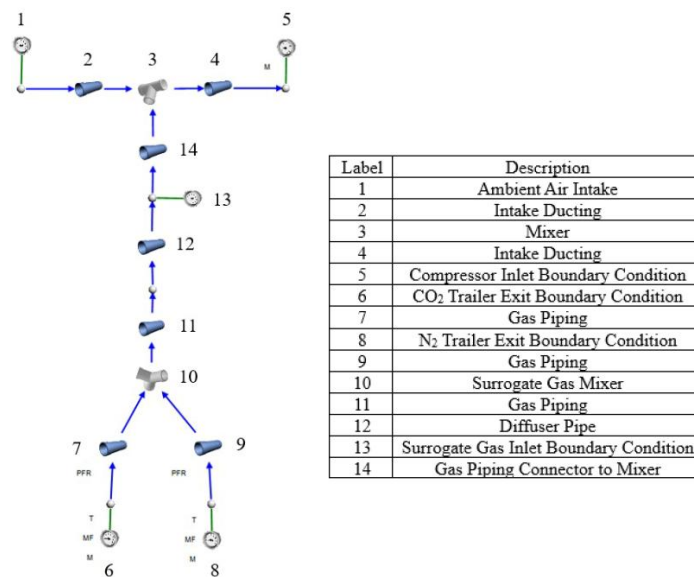


Figure 8: System B model

System B represents a laboratory-feasible surrogate EGR configuration in which bottled CO₂ and N₂ are vaporised, blended, and delivered to the turbine intake to reproduce the mixture entering the engine under EGR conditions. Ambient air enters the intake duct and merges with the surrogate gas stream before reaching the compressor inlet. The CO₂ and N₂ streams originate from vaporised reservoirs, pass through pressure-regulated supply lines, and combine at a mixing point before travelling through a long transfer pipe and diffuser toward the final intake mixer.

Flownex represented each part of the surrogate system using boundary conditions for ambient air and surrogate gas sources, pipe networks for the vaporised gas supply lines, junctions to model gas blending, a diffuser section to match the required mixing diameter, and a final T-junction where the surrogate mixture and ambient air converge before entering the compressor.

Key Findings

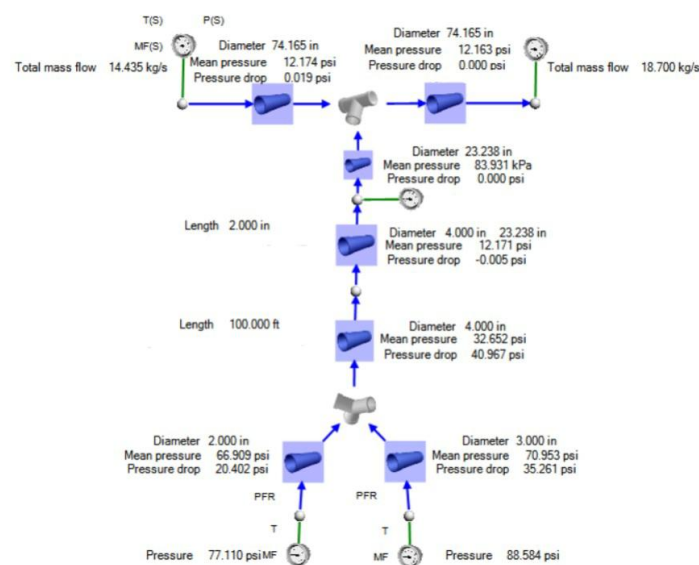


Figure 9: Analyses of the system B model

- **Pressure drop:** Total pressure loss to the compressor inlet was 916.13 Pa, well within allowable limits.
- **Pipe sizing:** The model identified minimum diameters for each segment to maintain acceptable velocities and pressure loss.
- **Inlet pressure requirements:** CO₂ and N₂ supply pressures solved to 111.54 kPa and 113.68 kPa, within standard supply capabilities.
- **Mixing:** The model indicated that full mixing can occur within the piping before reaching the compressor, reducing dependence on a dedicated static mixer.

The surrogate system was therefore shown to be feasible for controlled laboratory studies, subject to limitations on gas reservoir size and vaporiser capacity.

CONCLUSION

Flownex provided the modelling framework needed to evaluate both an application-based EGR retrofit and a surrogate EGR concept for a 3.5 MWe gas turbine.

The real EGR model quantified cooling requirements, pressure losses, and condensate behaviour and showed the system is technically feasible, but the cooling load (~8 MW) exceeds what the facility can currently provide.

The surrogate system model demonstrated that bottled CO₂ and N₂ can be mixed and delivered at the required flow and pressure conditions with acceptable pressure losses, making it a practical option for upcoming experimental work.

Combined with mixer design studies performed outside Flownex, these results form the basis for the next phase of experimentation, guiding component sizing, design decisions, and preparation for future EGR testing on the Centaur 40 engine.