

Caspian



Ceyhan

connection



Building the world's longest oil export pipeline from the Caspian to the Mediterranean is one of the most ambitious projects ever undertaken to help unlock the resources of an entire region.

Terry Knott focuses on some of the technical challenges involved in constructing and operating the 'line between two seas'

Joint by joint and day by day, the body of a vast steel pipeline is taking shape as it snakes across three different countries. Each day, remote construction crews add several kilometres to its length, passing through semi-desert, over high mountains and crossing great rivers. When the line is completed at the end of next year, it will run – unseen beneath the ground – for 1768km from the Sangachal terminal near Baku on the western shore of the Caspian Sea in Azerbaijan, via Tbilisi in Georgia, and on to the Mediterranean Sea port of Ceyhan in southern Turkey. In a few years' time, one million barrels of oil from the rich

reserves of the land-locked Caspian region will flow through the pipeline each day to world markets.

The construction activity, now in full swing since starting in May this year, represents the culmination of a project which has taken a decade to reach this stage. While extensive high-level negotiations were undertaken by the project's venture partners, led by BP, to achieve governmental and intergovernmental agreements and secure international financing, an abundance of engineering and scientific optimisation studies were carried out to ensure the best route was selected from technical, >>



>> environmental, social and security viewpoints. The manifestation of that decade of unrelenting effort is the Baku-Tbilisi-Ceyhan (BTC) pipeline project, a \$2.95 billion investment for which BP is the operator.

'BP has built some of the world's major pipelines, but this is the biggest we have ever done,' says Phil Allison, BP's project director for BTC. 'The primary driver for the line is to export the billions of barrels of oil reserves in the Caspian Sea – oil from the BP-operated Azeri, Chirag and Gunashli fields will be the first to flow through the line, scheduled to begin by early 2005. These fields have estimated reserves of 5.4 billion barrels of oil, a truly world scale development.'

'This is a long term investment; the pipeline is designed to operate for 40 years or more, attracting other business from the Caspian and perhaps beyond. In this respect, BTC will have positive and significant social and economic impacts throughout the region, especially in the three host countries it passes through.'

By the time it is completed, the pipeline's construction is expected to consume 52 million manhours of effort and employ over 10,000 people at peak, as construction teams from three main contracting groups work simultaneously at 17 different locations in the three countries. The project, which must deal with different laws, cultures, languages and practices in each nation, is being co-ordinated by a 500-strong management team in 17 project offices, shipping in linepipe and equipment from 13 countries, stretching from the USA and Canada to Japan and South Korea.

The impressive scale of the project is also reflected in the size of the pipeline itself.

From the Sangachal terminal near Baku, which will receive crude oil from the offshore fields, the line begins at 1070mm in diameter as it crosses semi-arid land in Azerbaijan, increases to 1170mm as it climbs into the Caucasus mountains in Georgia, steps down again to 1070mm for most of its journey across the Anatolian plateau in Turkey, and reduces to 865mm for final descent from the mountains to Ceyhan. Almost 150,000 joints of linepipe, each 12m in length, weighing some 655,000 tonnes, will be transported over difficult and remote terrain to be welded together to create the pipeline, which along its length will be buried to at least 1m deep in a specially constructed and reinstated trench – in some locations the trench will be up to 10m deep.

Over 100 block valves – these valves and their actuators typically measure 5m high and weigh around 30 tonnes – will be incorporated into the pipeline to enable it to be isolated in sections; and eight pumping stations along the route, each covering an area of 15-20 hectares, will boost the pressure of the oil to transport it over its undulating course, rising at its highest point of 2830m midway through Turkey.

Building the BTC oil pipeline is only part of the overall challenge. Once the line is completed in Azerbaijan and Georgia, the construction crews will 'about turn' and head back to Baku, building another pipeline – the South Caucasus Pipeline (SCP) – alongside

BTC, this one to carry natural gas from the Caspian to the Turkish border (see panel on page 24).

'The SCP will initially bring gas from the BP-operated Shah Deniz field in the Caspian, scheduled to start operations in 2006,' says Allison. 'At 690km long and 1070mm in diameter, this too is a major pipeline on the world scale. Aligning and combining the BTC and SCP projects has enabled us to take advantage of many synergies, for example the once-only mobilisation of construction crews. By doing this we have generated savings measured in hundreds of millions of dollars.'

BP operates major pipelines in several countries around the globe in areas as diverse as Alaska, the North Sea and Colombia, and is currently engaged in constructing a 520km-long, 1220mm-diameter gas export pipeline from the Sahara desert in Algeria. Indeed the company has recent experience of pipeline construction in the Caucasus region following the substantial renewal of the Western Route Export Pipeline in the mid-1990s, a 500mm-diameter pipeline which currently transports up to 150,000 barrels per day of Caspian crude oil from Baku to Supsa on the Georgian Black Sea coast.

'One of the many benefits of BTC is that it goes directly to the Mediterranean and therefore does not have to be taken by tanker through the highly congested Bosphorus and Turkish Straits to get to market,' Allison points out. 'Loading BTC oil at Ceyhan will avoid over 350 additional tanker cargoes per year passing through this narrow waterway, a move which brings with it safety and environmental benefits.'

Environmental and social considerations have exerted an important and often

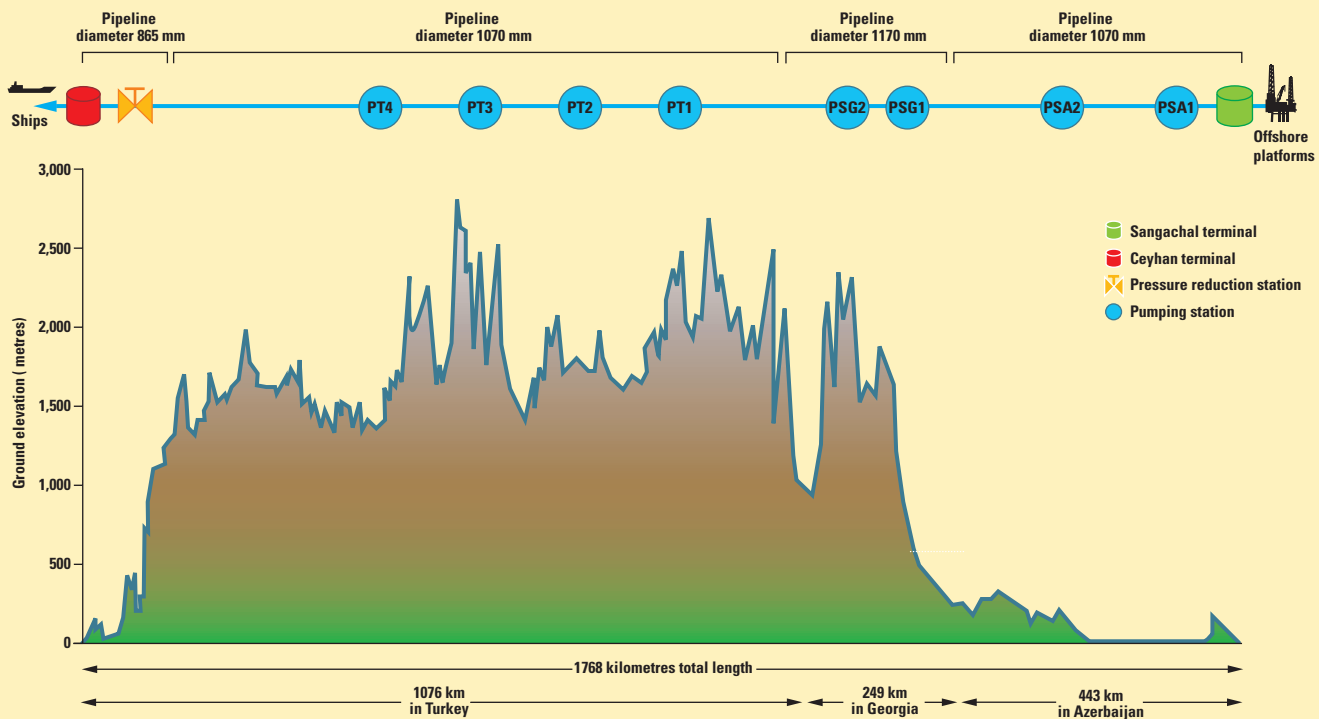
dominant influence on the land route of the BTC pipeline. The route was chosen using the technique of terrain evaluation, a BP best practice involving a multidisciplinary team investigating the many sections of the proposed pipeline corridor to

The BTC pipeline will avoid an increase in tanker traffic using the Bosphorus

establish in detail what lies along the route, particularly geohazards such as landslides and seismic faults. Pipeline engineers, geotechnical engineers, construction engineers, environmentalists, sociologists, archaeologists, botanists and zoologists worked together to refine the route, managing the geohazard risks and avoiding social and environmental impact as key guiding principles. The working corridor for

Scaling the heights

Ground elevation changes dramatically along the pipeline route, reaching 2830m in Turkey. Eight pumping stations will transport the oil through the line, which changes diameter four times in its 1768km journey.



installing the BTC pipeline is around 30m wide – 44m where SCP runs in parallel – but once the line is trenched and buried, the land above will be reinstated for use as before, apart from some restrictions on a narrow 8m wide strip above the line to protect it from accidental damage. The project team is proud of the outcome: no person will have to be displaced due to the pipeline routing.

Finding faults

But some features of the region cannot be avoided by any chosen route. Significantly for the pipeline's design engineers, these features include several active earthquake zones.

'The region is recognised as one of the most seismically active areas in the world,' notes Ian Parker, BP's engineering manager during the design stage of the project and now responsible for BTC's technical development programme. 'The pipeline crosses many active faults on its journey – three in Azerbaijan, four in Georgia and seven in Turkey. These have been identified and quantified by seismic specialists working with the project and BP's exploration and production technology group (E&PTG), and can take several forms.

'For example, the ground may move laterally along a slip plane, or can rise or fall vertically, imposing shear, tensile or compressive strains, or combinations thereof, on the buried pipeline (see panel on page 22).

By their nature, the faults can be surface-piercing and may create a zone which may be several hundreds of metres long that the pipeline must cross. Our challenge has been to design the line so that the strains are kept within acceptable limits, enabling the pipeline to withstand these events without rupture, should they occur.'

The design displacement for each fault varies widely, ranging from a 0.5m reverse fault near a 'mud volcano' in Azerbaijan, to a 2m reverse fault at Vale in Georgia, to the worst case of a 3m right lateral fault occurring on the Anatolian plateau in Turkey.

The technical solutions adopted to reduce the forces imposed on the pipeline are several. For example, reducing the angle at which the pipeline crosses the fault may help promote tension and reduce compression in the pipe. 'Flexibility' can be built into the line by installing it in a trapezoidal-section trench which reduces soil resistance along the pipeline and allows it to move more readily. Furthermore, the trench may be backfilled with rounded granular material which enables vertical and lateral movement to take place relative to the surrounding ground; the inclusion of geotextile membranes can enhance this movement in some cases.

In addition, the material grade, wall thickness and properties of the steel used for the pipeline at the fault crossings is selected to improve its load-carrying capabilities and

to provide better yield and tensile characteristics. For example, at Vale the pipeline's wall thickness will be 23.8mm, compared to the 12.7mm thickness generally used elsewhere. To validate the design assumptions made for the major fault crossing in Turkey, welded samples of the pipeline material are being physically tested.

Crossing courses

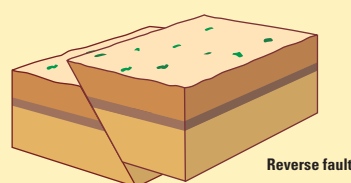
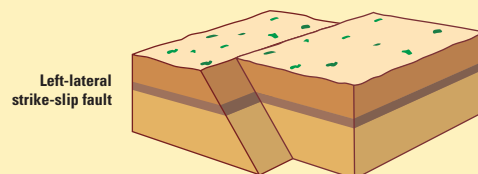
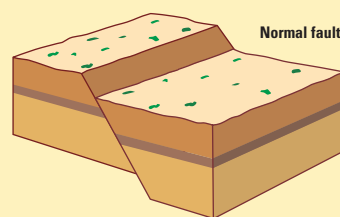
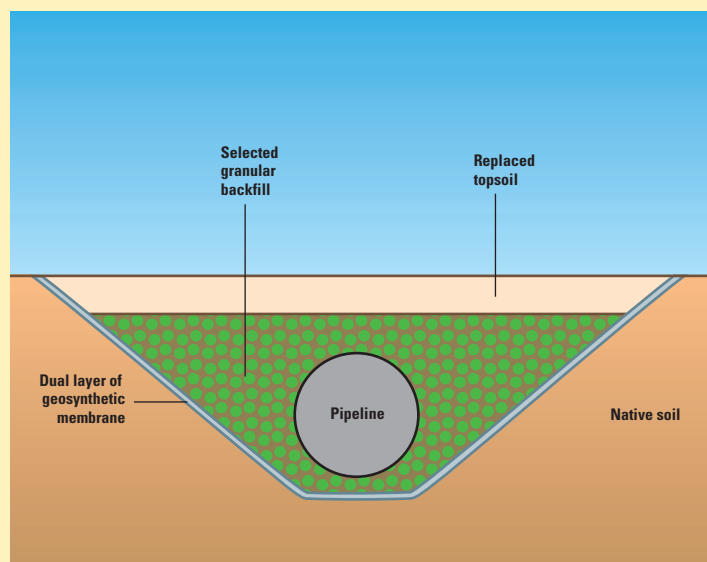
BTC's crossings are by no means confined to those in seismic zones. In all the BTC pipeline will also traverse over 3000 roads, railways and third party utility lines, some underground, some overhead. And then there are over 1500 watercourses to negotiate, ranging from small streams in mountain gorges which may disappear at certain times of year, to medium sized rivers and canals, to very large waterways such as the Kura River in Georgia or the Ceyhan River in Turkey, which at 5.2m deep and over 500m wide as it approaches the sea, is the BTC pipeline's widest river crossing.

Each watercourse crossing has been individually evaluated and designed in detail, using one of three basic methods of construction. The two most frequent will be dry open-cut crossings, involving the installation of temporary flumes in the bed of the watercourse to divert the river around the construction work; and wet open-cut crossings where the river bed can be

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Finding faults

Shown on the right are three examples of the many types of seismic faults which can occur in the region. In these areas the pipeline will be trenched as shown below to allow movement relative to the ground, reducing stresses imposed on the line.



>> excavated through the running water. The river beds will be reinstated to their pre-construction contours where possible and the backfill material will be at least as scour-resistant as the original beds.

The third method – horizontal directional drilling (HDD) – will be employed where larger or more sensitive watercourses must be traversed without disturbance (see panel on page 23). Six HDD crossings, which effectively pass below the river bed in the underlying rock or soils, are planned, five of them in Azerbaijan, including a 718m-long crossing of the Kura East river. The HDD technique begins with the drilling of a pilot hole at a shallow angle below the river bed, from one side of the crossing to the other (see figure). This is then reamed out to a diameter that will accommodate the sections of pipeline, already welded together. The sections are pulled through the hole by a winch, creating a continuous conduit beneath the watercourse.

To protect the entire pipeline against corrosion, an impressed current cathodic protection system will operate along the line, as used on many pipelines; the power for this system will be supplied from the pump stations and block valve stations. As a further

measure against corrosion, the pipe sections are also coated with a three-layer system of fusion bonded epoxy (FBE), adhesive, and an outer protective coating of polyethylene, some 4mm thick overall. Following evaluation trials supervised by E&PTG, gravel backfill materials of up to 22mm diameter were specified as being consistent with the robustness of the polyethylene, enabling a wider range of backfill materials to be used to reduce installation costs.

However, once the sections of pipe are welded together in the field, each of the welded field joints must also be protected.

'Traditionally, heat shrink sleeves have been used,' explains Parker, 'but these are not as resistant to damage as the polyethylene linepipe coating. So we conducted a test programme to find a

better alternative that can be applied to the field joints. The end result is that the pipe sections are supplied from the coating plants with the polyethylene coating cut back a short distance to expose the underlying FBE layer. Once the weld is made in the field, a liquid urethane modified epoxy can be sprayed or hand-applied across the weld which adheres to the exposed FBE layer as the primary barrier to moisture, but which also

sticks to the polyethylene as a secondary barrier. As far as we know, this is the first time that such a system has been employed.'

Go with the flow

While much of the focus at present is on constructing the BTC pipeline, the design has also paid equal attention to factors which will come into play once the pipeline moves into the operating phase.

Prominent among these design considerations is the nature of the crude oil from the Azeri, Chirag and Gunashli fields. The oil is non-Newtonian in its behaviour, similar to thixotropic 'non-drip' paint – it flows better as it is subjected to increasing shear forces. In practice this means that the oil will flow better at higher velocities when the pipeline is at design capacity – around 2m per second. The oil's viscosity is also directly affected by its temperature, with flow performance improving as temperature increases. At the Sangachal terminal the crude oil from the offshore fields is heated to assist in separating the gas from the oil to stabilise the crude for pipeline transportation, hence at the beginning of its journey the oil temperature is at least 30°C. But in the mountains during winter, the ambient air temperatures fall to -40°C, creating ground temperatures around -5°C. This causes the oil viscosity to increase and the fluid temperature profile along the route varies dramatically as a result.

The combination of low flowrates and

The pipeline must negotiate 14 seismic faults and over 1500 watercourses

therefore low shear, experienced during startup or after shutdowns, plus low temperatures, create conditions in which the oil can form a gel – the crude oil has a pour point of 12°C. While the pumps along the pipeline are sufficiently powerful to overcome this thickening effect, BP's studies into the flow characteristics of the crude oil have led to the adoption of a backup measure in the form of a chemical pour point depressant, which would be injected at Sangachal during line filling or prior to planned shutdowns.

In addition to tricky flow characteristics, the crude oil that will flow through the BTC pipeline also has a high wax content, 8-14% by volume, a small amount of which will deposit on the inner surface of the line. BP has experience of wax deposition in the Western Route Export Pipeline, and has correlated significant amounts of data about the way in which the wax is deposited – the deposition rate is driven by temperature difference, so that wax deposition is expected to be more prominent at the beginning of the line where the oil is initially hot, and at high elevations where the ambient temperatures are low.

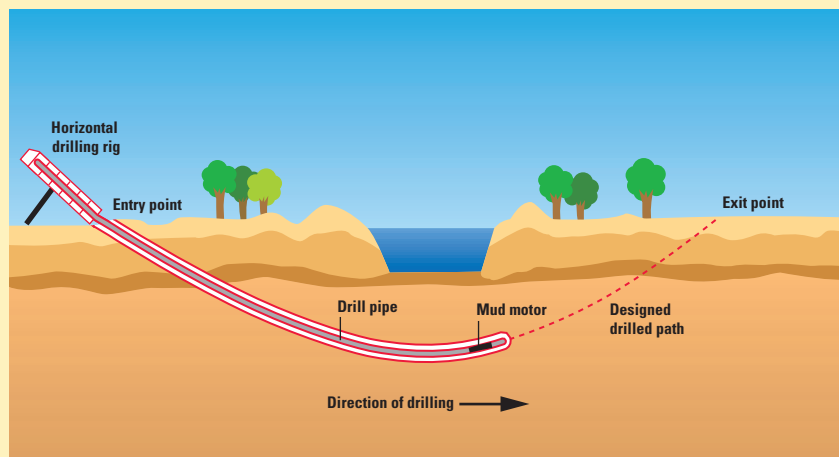
To clear the pipeline of deposited wax, which would build up over time, mechanical 'pigs' will be sent along inside sections of the line at regular intervals. These travel with the oil flow, scraping off and collecting the wax as they move forward. Each of the eight pumping stations will be equipped to launch and receive pigs, and two intermediate pigging stations are also being incorporated into the line, one in Azerbaijan and another in Turkey.

'Pigging is used in the Western Route Export Pipeline too, but the volumes are small enough for the collected wax to be removed from the pig receivers for safe disposal in drums,' Parker explains. 'But for BTC the wax volumes are predicted to be an order of magnitude higher and we expect to pig the line every few days. To manage the amount of wax generated we have developed a closed system which returns the wax to the crude oil flow, without manual intervention and without the need for wax disposal.'

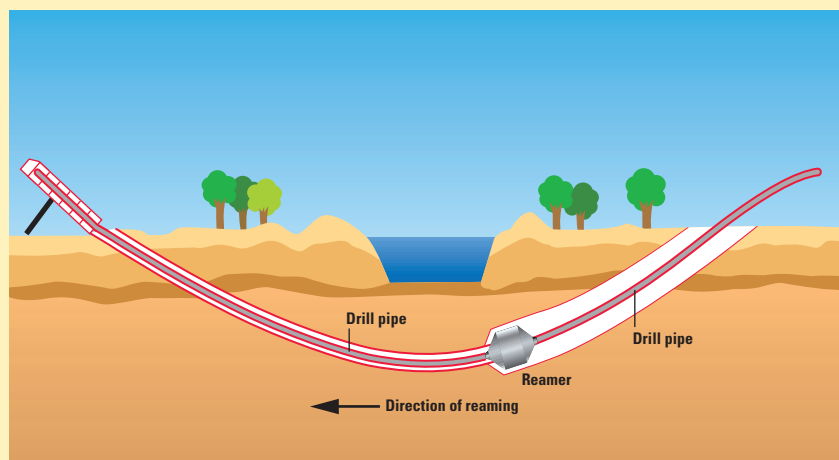
The wax handling system includes sets of injection nozzles located inside the pig receivers, as well as flushing systems for the pump strainers. Crude oil from the main pipeline is pumped through the nozzles to break up the collected wax, followed by hot oil injection to flush out the wax and dissolve it for return to the BTC pipeline – with the overall wax content of the crude oil being high, this relatively small return does not have any significant impact on the pipeline's transportation capability. Full scale trials of the new closed flushing system have >>

Crossing courses

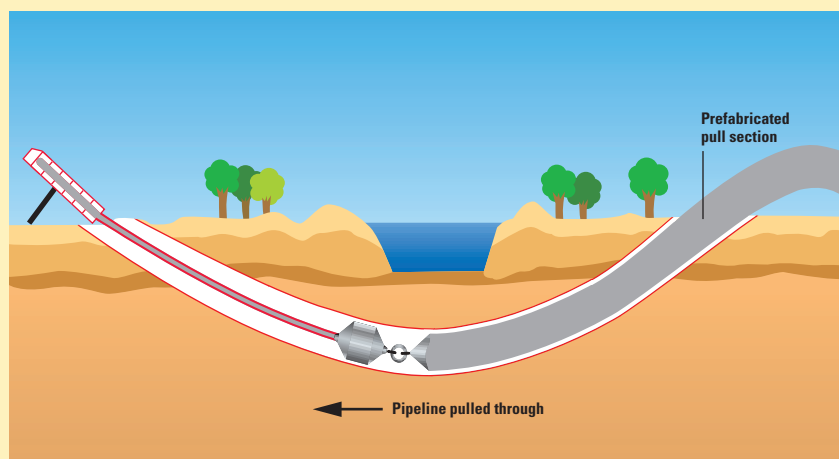
Horizontal directional drilling (the three main stages of which are shown in the graphics below) will be used to cross below larger or more sensitive watercourses.



Step 1: A pilot hole is drilled at a shallow angle below the river bed from one side of the crossing to the other.



Step 2: The hole is reamed out to increase its diameter to accommodate the pipeline.



Step 3: Sections of pipeline already welded together are pulled through the hole by a winch to create a continuous conduit beneath the river.

The first pipe sections of the BTC pipeline in Azerbaijan were laid into the trench in July 2003



>> been undertaken in the UK. The system will be deployed at all pigging stations, pumping stations, and the final pressure reduction station, which is located 125km from the end of the line to control the operating pressure as the pipeline makes its 1300m descent from the Anatolian plateau to Ceyhan.

Environmental drivers

One of the many tasks that will be undertaken from Sangachal is monitoring of the BTC

system for possible leaks from the pipeline. While these are very unlikely to occur, advanced technology has been built into the pipeline design to ensure any leak, large or small, will be detected very quickly, with appropriate measures for dealing with it laid out in the detailed BTC oil spill emergency response plan. The oil volumes moving through the line will be metered for fiscal purposes in each of the three countries and at the Ceyhan terminal. Alongside this

information, the BTC computerised leak detection system will generate further data by performing a mass balance on each section of line between pumping stations by measuring flows in and out of the pipeline section, corrected for pressure and temperature. In addition, pressure drop analysis techniques will be used to monitor pressure deviations, while an acoustic pressure wave system will detect any acoustic waves that are transmitted along the line in the event of a leak. And, as the pipeline is not a steady-state system due to the oil 'packing' and 'unpacking' as the line rides up and over mountains, real time transient modelling will be applied to check if the line is demonstrating an expected response to a given input.

'The leak detection system is very sophisticated, and needs to be in order to cope with the complex operating conditions in the pipeline,' Parker emphasises. 'For example, under steady low flowrate conditions below 500,000 barrels per day, as the pipeline traverses high elevations there will be insufficient liquid in the line to fill it on the downside of the mountain, known as slack line conditions. A type of channel flow is established; in a given section of pipeline it may appear, due to a temporary change in the operating conditions, that the flow going into the section does not equal the flow coming out. The leak detection method must allow for this in its calculations.'

Along the pipeline, 101 isolation valve stations will enable sections of the line to be closed off in the event of a leak. Most of the valves are ball valves, although where topography permits, check valves have been incorporated into the line on upslopes – these will close automatically if pipeline flow is disrupted, to prevent backflow into environmentally sensitive areas. The valves are not uniformly spaced along the pipeline,

The South Caucasus Pipeline (SCP)

The South Caucasus Pipeline (SCP) forms part of a \$3.2 billion, first stage project to develop the Shah Deniz gas field in the Azeri sector of the Caspian Sea and transport the gas to Turkey. The 690km-long, 1070mm-diameter SCP will run from Sangachal terminal near Baku through Georgia to the Turkish border, where the gas will enter the existing Turkish

gas distribution system. SCP, accounting for some \$900 million of the overall project cost, will follow the same route as the BTC oil pipeline, minimising environmental impact and achieving capital and operating cost savings. Gas from the line will eventually be used to power all of the pump stations along the route. Construction of the SCP will begin next year

and will be completed to deliver first gas to Turkey in 2006.

Recoverable reserves in the BP-operated Shah Deniz field are 625 billion cubic metres (bcm) of gas and 750 million barrels of condensate, with potential for further hydrocarbons at deeper geological horizons.

Offshore there will be a new 15-slot production, drilling and quarters

platform installed in 105m of water – the platform will be a TGP 500-type jackup installation – together with a subsequent five-well subsea development in 300m of water. Two new 100km-long pipelines, 650mm diameter for gas and 300mm diameter for condensate, will be built from the platform to shore to transport hydrocarbons to the Sangachal terminal

processing facilities. At maximum production, annual output from the development is expected to average 8.4bcm of gas plus 14.6 million barrels of condensate.

The partners in the Stage 1 project to develop the Shah Deniz gas field are BP (25.5%), Statoil (25.5%), Socar (10%), LUKAgip (10%), NICO (10%), Total (10%) and TPAO (9%).



Left: The first pipeline weld in Turkey, which took place in June 2003

Below: A computer visualisation of one of the eight pumping stations along the route, which will each cover 15-20 hectares



their locations being determined by quantitative risk analysis to optimise their positions; for example, as one of several protection measures in the area near the spa town of Borjomi and its mineral water springs, the number of valves has been doubled to four to add extra safeguards should any leak occur.

Power to operate the electrohydraulic actuated ball valves will be supplied from diesel generators, or grid supply where available. At each pumping station, three or four pumps rated at 5 to 7 megawatts each will be in operation to keep the oil flowing at the design capacity at pipeline pressures averaging 100 bar, and as high as 140 bar. In Turkey, the pumps will be driven by natural gas-fired reciprocating engines, using gas from the existing East Anatolian Natural Gas Pipeline. In Azerbaijan and Georgia, the drivers will be dual fuel engines, capable of burning either diesel or natural gas. At the start of operations, these drivers will run on diesel produced from oil extracted from the pipeline, in 'crude oil topping units' – fractionation columns – located at the pump stations. Once the SCP is completed, natural gas will become available to run the dual fuel engines, reducing atmospheric emissions, another key environmental target for the project.

'By choosing dual fuel efficient turbines we managed to reduce the amount of carbon dioxide emitted from the pumping stations by almost 40%,' observes Allison. 'By increasing the pipeline diameter in Georgia to 1170mm, we eliminated a complete pumping station and its associated emissions. And at the loading terminal in Ceyhan we recover hydrocarbon vapours – which are far more damaging to the environment than carbon dioxide – and convert these

to carbon dioxide by burning them in a safe and highly efficient ground flare.'

The new marine export terminal at Ceyhan will have capacity to load two very large crude tankers simultaneously, each at a rate of 60,000 barrels of oil per hour, from a jetty reaching out 2.5km into the sea. Seven new crude storage tanks, each with capacity of 950,000 barrels, are being constructed at the terminal. At Sangachal, two new storage tanks of 800,000 barrels capacity, will join four existing smaller tanks.

When the BTC pipeline is in full operation at the end of this decade, the oil's journey time from Baku to Ceyhan will be around ten days, as the daily delivery of one million barrels of oil arrives from the Caspian. But already BP and its partners are studying ways to increase the throughput of the pipeline. Such is the prolific nature of the Caspian's hydrocarbon resources. And such is the importance of bringing these to world markets through the corridor of energy created by the region's export pipelines. ■

BTC partners and main contractors

Participants in the BTC pipeline project are:

• BP (operator, UK)	30.1%
• SOCAR (Azerbaijan)	25%
• Unocal (USA)	8.9%
• Statoil (Norway)	8.71%
• TPAO (Turkey)	6.53%
• Total (France)	5.0%
• Agip (Italy)	5.0%
• Itochu (Japan)	3.4%
• Conoco Phillips (USA)	2.5%
• INPEX (Japan)	2.5%
• Amerada Hess (USA)	2.36%

The BTC Pipeline Company, led by BP, is responsible for the construction and operation of the entire pipeline. Several main contractors are assisting with the project:

John Brown Hydrocarbons and Bechtel in London together provide engineering and procurement services for

the Azerbaijan and Georgian sections of the pipeline and facilities. In Turkey, national oil and gas pipeline company BOTAS is BP's primary turnkey contractor. BOTAS awarded subcontracts to Temelsu and Yuksel of Turkey and to ILF of Germany for detailed engineering design. Bechtel has a system engineering assurance role across all three countries.

The main pipelay contracts were awarded in August 2002. In Azerbaijan, the work is being carried out by Consolidated Contractors International, based in Athens, while French-US joint venture Spie Capag/Petrofac is installing the line in Georgia – the joint venture is also responsible for building the pumping stations and above-ground facilities in

both countries.

In Turkey, pipeline installation is subdivided into three lots: to Tepe-Nacap, a Turkish-Dutch joint venture, laying 278km of line from the Georgian border; Gunsayil-Haudstadt Timmerman-Max Streicher-Alarko, a Turkish-German joint venture, will lay the next 471km of pipeline; Punj Lloyd-Limak, an Indian-Turkish joint venture, will install the final 327km to Ceyhan. Facilities in Turkey will be constructed by Tepe.

For the Sangachal terminal, Kellogg Brown & Root of the US is responsible for engineering and procurement, while Tekfen/Azfen, of Turkey and Azerbaijan, are building the new facilities. In Ceyhan, the new export terminal is being constructed by Tekfen.

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