



Environmental, Health and Safety Guidelines for Coal Processing

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)¹. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them. The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables,

¹ Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment

Applicability

The EHS Guidelines for Coal Processing cover the processing of coal into gaseous or liquid chemicals, including fuels. They apply to the production of Synthetic Gas (SynGas) through various gasification processes and its subsequent conversion into liquid hydrocarbons (Fischer-Tropsch synthesis), methanol, or other oxygenated liquid products, as well as to the direct hydrogenation of coal into liquid hydrocarbons.

This document is organized according to the following sections:

- Section 1.0 — Industry-Specific Impacts and Management
- Section 2.0 — Performance Indicators and Monitoring
- Section 3.0 — References and Additional Sources
- Annex A — General Description of Industry Activities

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with coal processing, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phase(s) are provided in the **General EHS Guidelines**.

1.1 Environmental

Potential environmental issues associated with coal processing projects include:

- Air emissions
- Wastewater
- Hazardous materials
- Wastes
- Noise

Air Emissions

Fugitive Particulate Matter and Gaseous Emissions

The main sources of emissions in coal processing facilities primarily consist of fugitive sources of particulate matter (PM), volatile organic compounds (VOCs), carbon monoxide (CO), and hydrogen. Coal transfer, storage, and preparation activities may contribute significantly to fugitive emissions of coal PM. Recommendations to prevent and control fugitive coal PM emissions include the following:

- Design of the plant or facility layout to facilitate emissions management and to reduce the number of coal transfer points;
- Use of loading and unloading equipment to minimize the height of coal drop to the stockpile;

- Use of water spray systems and/or polymer coatings to reduce the formation of fugitive dust from coal storage (e.g. on stockpiles) as feasible depending on the coal quality requirements;
- Capture of coal dust emissions from crushing / sizing activities and conveying to a baghouse filter or other particulate control equipment;
- Use of centrifugal (cyclone) collectors followed by high-efficiency venturi aqueous scrubbers for thermal dryers;
- Use of centrifugal (cyclone) collectors followed by fabric filtration for pneumatic coal cleaning equipment;
- Use of enclosed conveyors combined with extraction and filtration equipment on conveyor transfer points; and
- Suppression of dust during coal processing (e.g., crushing, sizing, and drying) and transfer (e.g., conveyor systems) using, for example, water spraying systems with water collection and subsequent treatment or re-use of the collected water.

Fugitive emissions of other air pollutants include leaks of volatile organic compounds (VOC), carbon monoxide (CO), and hydrogen from various processes such as SynGas production units; coal storage; methanol and Fischer-Tropsch (F-T) synthesis units; product upgrading units; and oily sewage systems and wastewater treatment facilities, particularly equalization ponds and oil / water separators. Fugitive emissions may also include leaks from numerous sources including piping, valves, connections, flanges, gaskets, open-ended lines, storage and working losses from fixed and floating roof storage tanks and pump seals, gas conveyance systems, compressor seals, pressure relief valves, open pits / containments, and loading and unloading of hydrocarbons.

Recommendations to prevent and control fugitive sources of air pollutants include:

- Reduce fugitive emissions from pipes, valves, seals, tanks, and other infrastructure components by regularly monitoring with vapor detection equipment and maintenance or replacement of components as needed in a prioritized manner;
- Maintain stable tank pressure and vapor space by:
 - Coordination of filling and withdrawal schedules and implementing vapor balancing between tanks, (a process whereby vapor displaced during filling activities is transferred to the vapor space of the tank being emptied or to other containment in preparation for vapor recovery);
 - Use of white or other color paints with low heat absorption properties on exteriors of storage tanks for lighter distillates such as gasoline, ethanol, and methanol to reduce heat absorption. Potential for visual impacts from reflection of light off tanks should be considered;
- Based on the tank storage capacity and vapor pressure of materials being stored, select a specific tank type to minimize storage and working losses according to internationally accepted design standards.²
- For fixed roof storage tanks, minimize storage and working losses by installation of an internal floating roof and seals³;

² For example, according to API Standard 650: Welded Steel Tanks for Oil Storage (1998), new, modified, or restructured tanks with a capacity greater or equal to 40,000 gallons and storing liquids with a vapor pressure greater or equal than 0.75 psi but less than 11.1 psi, or a capacity greater or equal to 20,000 gallons and storing liquids with a vapor pressure greater or equal than 4 psi but less than 11.1 psi must be equipped with: fixed roof in conjunction with an internal floating roof with a liquid mounted mechanical shoe primary seal; or external floating roof with a liquid mounted mechanical shoe primary seal and continuous rim-mounted secondary seal, with both seals meeting certain minimum gap requirements and gasketed covers on the roof fittings; or closed vent system and 95% effective control device.

³ Worker access into tanks should be conducted following permit-required confined space entry procedures as noted in the General EHS Guidelines.

- For floating roof storage tanks, design and install decks, fittings, and rim seals in accordance with international standards to minimize evaporative losses;⁴
- Consider use of supply and return systems, vapor recovery hoses, and vapor tight trucks / railcars / vessels during loading and unloading of transport vehicles;
- Use bottom loading truck / rail car filling systems to minimize vapor emissions; and
- Where vapor emissions may contribute or result in ambient air quality levels above health based standards, consider installation of secondary emissions controls, such as vapor condensing and recovery units, catalytic oxidizers, gas adsorption media, refrigeration, or lean oil absorption units.

Greenhouse Gases (GHGs)

Significant amounts of carbon dioxide (CO₂) may be produced in SynGas manufacturing, particularly during the water-gas shift reaction, in addition to all combustion-related processes (e.g., electric power production and by-product incineration or use in co-generation). Recommendations for energy conservation and the management of greenhouse gas emissions are project and site-specific but may include some of those discussed in the **General EHS Guidelines**. At integrated facilities, operators should explore an overall facility approach in the selection of process and utility technologies.

Particulate Matters, Heavy Oils, and Heavy Metals

Coal preparation activities (e.g., use of dryers), coal gasification (e.g., feeding and ash removal), and coal liquefaction processes may generate point-source emissions of dust and heavy oils (tars). Appropriate technology should be selected to minimize

⁴ Examples include: API Standard 620: Design and Construction of Large, Welded, Low-pressure Storage Tanks (2002); API Standard 650: Welded Steel Tanks for Oil Storage (1998), and; European Union (EU) European Standard (EN) 12285-2:2005. Workshop fabricated steel tanks for the aboveground storage of flammable and non-flammable water polluting liquids (2005).

particulate emissions. Heavy metals present in coal may be released as air emissions from the coal gasification process.

Most heavy metals can be removed through a wet scrubber. Absorption technology may be required to remove mercury in coal with higher mercury content. The particulate matter control recommendations are addressed in the **General EHS**

Guidelines.

Acid Gases and Ammonia

Off-gas stack emissions from the Claus Sulfur Recovery Unit include a blend of inert gases containing sulfur dioxide (SO₂) and are a significant source of air emissions during coal processing. The gasification process may also generate pollutants such as hydrogen sulfide (H₂S), carbonyl sulfide (COS), carbon disulfide (CS₂), carbon monoxide (CO), ammonia (NH₃), and hydrogen cyanide (HCN). Typically, these gases are highly recoverable during SynGas purification (>99 percent). Liquefaction processes, including operations at the slurry mix tanks, may result in releases of other acid gases and volatile organics. Recommended acid gas and ammonia emissions management strategies include:

- Installation of a sulfur recovery process to avoid emissions of H₂S (e.g., Claus);
- Venting of the slurry mix tanks to combustion air supplies for power or heat generation;
- Installation of scrubbing processes, either oxidation tailgas scrubbers or reduction tailgas scrubbers, as well as Venturi scrubbers, to reduce emissions of sulfur dioxides;
- If installing incineration devices for removal of sulfur, operate the incinerator at temperatures of 650 degrees Celsius (°C) or higher with proper air-to-fuel ratios in order to completely combust H₂S; and

- Equip stacks with access for the operation of monitoring devices (e.g., to monitor SO₂ emissions from the Claus process and incinerators).

Exhaust Gases

Combustion of SynGas or gas oil for power and heat generation at coal processing facilities is a significant source of air emissions, including CO₂, nitrogen oxides (NO_x), SO₂, and, in the event of burner malfunction, carbon monoxide (CO).

Guidance for the management of small combustion processes designed to deliver electrical or mechanical power, steam, heat, or any combination of these, regardless of the fuel type, with a total rated heat input capacity of 50 Megawatt thermal (MWth) is provided in the **General EHS Guidelines**. Guidance applicable to processes larger than 50 MWth is provided in the **EHS Guidelines for Thermal Power**.

Emissions related to the operation of power sources should be minimized through the adoption of a combined strategy which includes a reduction in energy demand, use of cleaner fuels, and application of emissions controls where required. Recommendations on energy efficiency are addressed in the **General EHS Guidelines**.

Venting and Flaring

Venting and flaring are an important operational and safety measure used in coal processing facilities to ensure gas is safely disposed of in the event of an emergency, power or equipment failure, or other plant upset conditions. Unreacted raw materials and by-product combustible gases are also disposed of through venting and flaring. Excess gas should not be vented but instead sent to an efficient flare gas system for disposal.

Recommendations to minimize gas venting and flaring include the following:

- Optimize plant controls to increase the reaction conversion rates;
- Utilize unreacted raw materials and by-product combustible gases for power generation or heat recovery, if possible;
- Provide back-up systems to maximize plant reliability; and
- Locate flaring systems at a safe distance from personnel accommodations and residential areas and maintain flaring systems to achieve high efficiency.

Emergency venting may be acceptable under certain conditions where flaring of the gas stream is not appropriate. Standard risk assessment methodologies should be utilized to analyze such situations. Justification for not using a gas flaring system should be fully documented before an emergency gas venting facility is considered.

Wastewater

Industrial Process Wastewater

Process wastewater may become contaminated with hydrocarbons, ammonia and amines, oxygenated compounds, acids, inorganic salts, and traces of heavy metal ions.

Recommended process wastewater management practices include:

- Prevention of accidental releases of liquids through inspections and maintenance of storage and conveyance systems, including stuffing boxes on pumps and valves and other potential leakage points, as well as the implementation of spill response plans;
- Provision of sufficient process fluids let-down capacity to maximize recovery into the process and to avoid massive

process liquids discharge into the oily water drain system; and

- Design and construction of wastewater and hazardous materials storage containment basins with impervious surfaces to prevent infiltration of contaminated water into soil and groundwater.

Specific provisions for the management of individual wastewater streams include the following:

- Amines spills resulting from the carbon dioxide alkaline removal system downstream of the Gasification Unit should be collected into a dedicated closed drain system and, after filtration, recycled back into the process;
- Effluent from the stripping column of the F-T Synthesis Unit, which contains dissolved hydrocarbons and oxygenated compounds (mainly alcohols and organic acids) and minor amounts of ketones, should be re-circulated inside the F-T Synthesis Unit to recover the hydrocarbons and oxygenated compounds in a stripping column;
- Acidic and caustic effluents from demineralized water preparation, the generation of which depends on the quality of the raw water supply to the process, should be neutralized prior to discharge into the facility's wastewater treatment system;
- Blow-down from the steam generation systems and cooling towers should be cooled prior to discharge. Cooling water containing biocides or other additives may also require does adjustment or treatment in the facility's wastewater treatment plant prior to discharge; and
- Hydrocarbon-contaminated water from scheduled cleaning activities during facility turn-around (cleaning activities are typically performed annually and may last for a few weeks), oily effluents from process leaks, and heavy-metals

containing effluents from fixed and fluidized beds should be treated via the facility's wastewater treatment plant.

Process Wastewater treatment

Techniques for treating industrial process wastewater in this sector include source segregation and pretreatment of concentrated wastewater streams. Typical wastewater treatment steps include: grease traps, skimmers, dissolved air floatation, or oil / water separators for separation of oils and floatable solids; filtration for separation of filterable solids; flow and load equalization; sedimentation for suspended solids reduction using clarifiers; biological treatment, typically aerobic treatment, for reduction of soluble organic matter (BOD); chemical or biological nutrient removal for reduction in nitrogen and phosphorus; chlorination of effluent when disinfection is required; and dewatering and disposal of residuals in designated hazardous waste landfills. Additional engineering controls may be required for (i) containment and treatment of volatile organics stripped from various unit operations in the wastewater treatment system, (ii) advanced metals removal using membrane filtration or other physical/chemical treatment technologies, (iii) removal of recalcitrant organics, cyanide and non biodegradable COD using activated carbon or advanced chemical oxidation, (iii) reduction in effluent toxicity using appropriate technology (such as reverse osmosis, ion exchange, activated carbon, etc.), and (iv) containment and neutralization of nuisance odors.

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document. Recommendations to reduce water consumption,

especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Other Wastewater Streams & Water Consumption

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the General EHS Guidelines. Contaminated streams should be routed to the treatment system for industrial process wastewater. Additional specific guidance is provided below.

Stormwater: Stormwater may become contaminated as a result of spills of process liquids as well as migration of leachate containing hydrocarbons and heavy metals from coal storage areas. Industry-specific recommendations include:

- Pave process areas, segregate contaminated and non-contaminated stormwater, and implement spill control plans. Route stormwater from process areas into the wastewater treatment unit; and
- Design and locate coal storage facilities and associated leachate collection systems to prevent impacts to soil and water resources. Coal stockpile areas should be paved to segregate potentially contaminated stormwater, which should be transferred to the facility's wastewater treatment unit.

Cooling water: Cooling water may result in high rates of water consumption, as well as the potential release of high temperature water, residues of biocides, and residues of other cooling system anti-fouling agents. Recommended cooling water management strategies include:

- Adoption of water conservation opportunities for facility cooling systems as provided in the **General EHS Guidelines**;

- Use of heat recovery methods (also energy efficiency improvements) or other cooling methods to reduce the temperature of heated water prior to discharge to ensure the discharge water temperature does not result in an increase greater than 3°C of ambient temperature at the edge of a scientifically established mixing zone that takes into account ambient water quality, receiving water use, assimilative capacity, etc.;
- Minimizing use of antifouling and corrosion-inhibiting chemicals by ensuring appropriate depth of water intake and use of screens; selection of the least hazardous alternatives with regards to toxicity, biodegradability, bioavailability, and bioaccumulation potential; and dosing in accordance with local regulatory requirements and manufacturer recommendations; and
- Testing for residual biocides and other pollutants of concern to determine the need for dose adjustments or treatment of cooling water prior to discharge.

Hydrostatic testing water: Hydrostatic testing (hydro-test) of equipment and pipelines involves pressure testing with water (generally filtered raw water) to verify their integrity and detect possible leaks. Chemical additives, typically a corrosion inhibitor, an oxygen scavenger, and a dye, may be added. In managing hydro-test waters, the following pollution prevention and control measures should be implemented:

- Reuse water for multiple tests to conserve water and minimize discharges of potentially contaminated effluent;
- Reduce use of corrosion inhibiting or other chemicals by minimizing the time that test water remains in the equipment or pipeline; and
- Select the least hazardous alternatives with regard to toxicity, biodegradability, bioavailability, and bioaccumulation potential, and dosing in accordance with

local regulatory requirements and manufacturer recommendations.

If discharge of hydro-test waters to the sea or to surface water is the only feasible option for disposal, a hydro-test water disposal plan should be prepared considering location and rate of discharge, chemical use and dispersion, environmental risk, and required monitoring. Hydro-test water disposal into shallow coastal waters should be avoided.

Hazardous Materials

Coal processing facilities manufacture significant amounts of hazardous materials, including intermediate / final products and by-products. The handling, storage, and transportation of these materials should be managed properly to avoid or minimize the environmental impacts from these hazardous materials.

Recommended practices for hazardous material management, including handling, storage, and transport are provided in the **General EHS Guidelines**.

Wastes

Non-hazardous wastes include coal bottom ash, slag, fly ash, and coal storage sludge. Coal bottom ash and slag⁵ are the coarse, granular, incombustible by-products that are collected from the bottom of gasifiers. Fly ash is also captured from the reactor. The amount of generated slag and ashes is typically significant and depends on the grade of coal used in the plant. The physical form of the ash is related to the gasification process.

Potentially hazardous wastes typically include spent catalysts, oil, solvents, reactant solutions, filters, saturated filtering beds, heavy-ends from the synthesis purification, used containers, oily rags, mineral spirits, used sweetening, spent amines for CO₂

⁵ Recycling Materials Resource Center (RMRC), Coal Bottom Ash/Boiler Slag, available at <http://www.rmrc.unh.edu/Partners/UserGuide/cbabs1.htm>

removal, activated carbon filters and oily sludge from oil water separators, and spent or used operational and maintenance fluids such as oils and test liquids, and wastewater treatment sludge.

General recommendations for the management of hazardous and non-hazardous waste are presented in the **General EHS Guidelines**. Industry-specific waste management practices include the following.

Coal Bottom Ash, Slag, and Fly Ash

Depending on their toxicity and radioactivity, coal bottom ash, slag, and fly ash may be recycled, given the availability of commercially and technical viable options. Recommended recycling methods include:

- Use of bottom ash as an aggregate in lightweight concrete masonry units, as raw feed material in the production of Portland cement, road base and sub-base aggregate, or as structural fill material, and as fine aggregate in asphalt paving and flowable fill;
- Use of slag as blasting grit, as roofing shingle granules, for snow and ice control, as aggregate in asphalt paving, as a structural fill, and in road base and sub-base applications;
- Use of fly ash in construction materials requiring a pozzolanic material.

Where due to its toxic / radioactive characteristics or unavailability of commercially and technically viable alternatives these materials can not be recycled, they should be disposed of in a licensed landfill facility designed and operated according to good international industry practice.⁶

⁶ Additional guidance on the disposal of hazardous and non-hazardous industrial waste is provided in the **EHS Guidelines for Waste Management Facilities**.

Coal Storage Sludge

Coal dust sludge generated from coal storage and coal preparation should be dried and reused or recycled where feasible. Possible options may include reuse as feedstock in the gasification process, depending on the gasification technology selected. Handling, transport, and on-site / off-site management of all sludge should be conducted according to the non-hazardous industrial waste management recommendations included in the **General EHS Guidelines**.

Spent Catalysts

Spent catalysts result from catalyst bed replacement in scheduled turnarounds of SynGas desulphurization, Fischer – Tropsch (F-T) reaction, isomerization, catalytic cracking, and methanol syntheses. Spent catalysts may contain zinc, nickel, iron, cobalt, platinum, palladium, and copper, depending on the particular process.

Recommended waste management strategies for spent catalysts include the following:

- Appropriate on-site management, including submerging pyrophoric spent catalysts in water during temporary storage and transport until they can reach the final point of treatment to avoid uncontrolled exothermic reactions;
- Return to the manufacturer for regeneration; and
- Off-site management by specialized companies that can recover the heavy or precious metals, through recovery and recycling processes whenever possible, or who can otherwise manage spent catalysts or their non-recoverable materials according to hazardous and non-hazardous waste management recommendations presented in the **General EHS Guidelines**. Catalysts that contain platinum or palladium should be sent to a noble metals recovery facility.

Heavy Ends

Heavy ends from the purification section of the Methanol Synthesis Unit are normally burnt in a steam boiler by means of a dedicated burner.

Noise

The principal sources of noise in coal processing facilities include the physical processing of coal (e.g. screening, crushing, sizing and sorting), as well as large rotating machines (e.g., compressors, turbines, pumps, electric motors, air coolers, and fired heaters). During emergency depressurization, high noise levels can be generated due to release of high-pressure gases to flare and / or steam release into the atmosphere. General recommendations for noise management are provided in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Facility-specific occupational health and safety hazards should be identified based on job safety analysis or comprehensive hazard or risk assessment using established methodologies such as a hazard identification study [HAZID], hazard and operability study [HAZOP], or a scenario-based risk assessment [QRA].

As a general approach, health and safety management planning should include the adoption of a systematic and structured system for prevention and control of physical, chemical, biological, and radiological health and safety hazards described in the **General EHS Guidelines**.

The most significant occupational health and safety hazards occur during the operational phase of a coal processing facility and primarily include the following:

- Process Safety
- Oxygen-Enriched Gas Releases

- Oxygen-Deficient Atmospheres
- Inhalation hazards
- Fire and explosions

Process Safety

Process safety programs should be implemented due to industry-specific characteristics, including complex chemical reactions, use of hazardous materials (e.g., toxic, reactive, flammable or explosive compounds), and multi-step reactions. Process safety management includes the following actions:

- Physical hazard testing of materials and reactions;
- Hazard analysis studies to review the process chemistry and engineering practices, including thermodynamics and kinetics;
- Examination of preventive maintenance and mechanical integrity of the process equipment and utilities;
- Worker training; and
- Development of operating instructions and emergency response procedures.

Oxygen-Enriched Gas Releases

Oxygen-enriched gas may leak from air separation units and create a fire risk due to an oxygen-enriched atmosphere.

Oxygen-enriched atmospheres may potentially result in the saturation of materials, hair, and clothing with oxygen, which may burn vigorously if ignited. Prevention and control measures to reduce on-site and off-site exposure to oxygen-enriched atmospheres include:

- Installation of an automatic Emergency Shutdown System that can detect and warn of the uncontrolled release of oxygen (including the presence of oxygen enriched

atmospheres in working areas⁷) and initiate shutdown actions thus minimizing the duration of releases, and elimination of potential ignition sources;

- Design of facilities and components according to applicable industry safety standards, avoiding the placement of oxygen-carrying piping in confined spaces, using intrinsically safe electrical installations, and using facility-wide oxygen venting systems that properly consider the potential impact of the vented gas;
- Implementation of hot work and permit-required confined space entry procedures that specifically take into account the potential release of oxygen;
- Implementation of good housekeeping practices to avoid accumulation of combustible materials;
- Planning and implementation of emergency preparedness and response plans that specifically incorporate procedures for managing uncontrolled releases of oxygen; and
- Provision of appropriate fire prevention and control equipment as described below (Fire and Explosion Hazards).

Oxygen-Deficient Atmosphere

The potential releases and accumulation of nitrogen gas into work areas can result in asphyxiating conditions due to the displacement of oxygen by these gases. Prevention and control measures to reduce risks of asphyxiant gas release include:

- Design and placement of nitrogen venting systems according to recognized industry standards;

- Installation of an automatic Emergency Shutdown System that can detect and warn of the uncontrolled release of nitrogen (including the presence of oxygen deficient atmospheres in working areas⁸), initiate forced ventilation, and minimize the duration of releases; and
- Implementation of confined space entry procedures as described in the **General EHS Guidelines** with consideration of facility-specific hazards.

Inhalation Hazards

Chemical exposure in coal processing facilities is primarily related to inhalation of coal dust, coal tar pitch volatiles, carbon monoxide, and other vapors such as methanol and ammonia. Workers exposed to coal dust may develop lung damage and pulmonary fibrosis. Exposure to carbon monoxide results in formation of carboxyhemoglobin (COHb), which inhibits the oxygen-carrying ability of the red blood cells. Mild exposure symptoms may include headache, dizziness, decreased vigilance, decreased hand-eye coordination, weakness, confusion, disorientation, lethargy, nausea, and visual disturbances. Greater or prolonged exposure can cause unconsciousness and death.

Potential inhalation exposures to chemicals emissions during routine plant operations should be managed based on the results of a job safety analysis and industrial hygiene survey, and according to occupational health and safety guidance provided in the **General EHS Guidelines**. Protection measures include worker training, work permit systems, use of personal protective equipment (PPE), and toxic gas detection systems with alarms.

⁷ Working areas with the potential for oxygen enriched atmospheres should be equipped with area monitoring systems capable of detecting such conditions. Workers also should be equipped with personal monitoring systems. Both types of monitoring systems should be equipped with a warning alarm set at 23.5 percent concentration of O₂ in air.

⁸ Working areas with the potential for oxygen deficient atmospheres should be equipped with area monitoring systems capable of detecting such conditions. Workers also should be equipped with personal monitoring systems. Both types of monitoring systems should be equipped with a warning alarm set at 19.5 percent concentration of O₂ in air.

Fire and Explosion Hazards

Coal Storage and Preparation

Coal is susceptible to spontaneous combustion, most commonly due to oxidation of pyrite or other sulphidic contaminants in coal.^{9, 10} Coal preparation operations also present a fire and explosion hazard due to the generation of coal dust, which may ignite depending on its concentration in air and presence of ignition sources. Coal dust therefore represents a significant explosion hazard in coal storage and handling facilities where coal dust clouds may be generated in enclosed spaces. Dust clouds also may be present wherever loose coal dust accumulates, such as on structural ledges. Recommended techniques to prevent and control combustion and explosion hazards in enclosed coal storage include the following:

- Storing coal piles so as to prevent or minimize the likelihood of combustion, including:
 - Compacting coal piles to reduce the amount of air within the pile,
 - Minimizing coal storage times,
 - Avoiding placement of coal piles above heat sources such as steam lines or manholes,
 - Constructing coal storage structures with non-combustible materials,
 - Designing coal storage structures to minimize the surface areas on which coal dust can settle and providing dust removal systems, and
 - Continuous monitoring for hot spots (ignited coal) using temperature detection systems. When a hot spot is detected, the ignited coal should be removed. Access should be provided for firefighting;

- Eliminating the presence of potential sources of ignition, and providing appropriate equipment grounding to minimize static electricity hazards. All machinery and electrical equipment inside the enclosed coal storage area or structure should be approved for use in hazardous locations and provided with spark-proof motors;
- All electrical circuits should be designed for automatic, remote shutdown; and
- Installation of an adequate lateral ventilation system in enclosed storage areas to reduce concentrations of methane, carbon monoxide, and volatile products from coal oxidation by air, and to deal with smoke in the event of a fire.

Recommended techniques to prevent and control explosion risks due to coal preparation in an enclosed area include the following:

- Conduct dry coal screening, crushing, dry cleaning, grinding, pulverizing and other operations producing coal dust under nitrogen blanket or other explosion prevention approaches such as ventilation;
- Locate the facilities to minimize fire and explosion exposure to other major buildings and equipment;
- Consider controlling the moisture content of coal prior to use, depending on the requirements of the gasification technology;
- Install failsafe monitoring of methane concentrations in air, and halt operations if a methane concentration of 40 percent of the lower explosion limit is reached;
- Install and properly maintain dust collector systems to capture fugitive emissions from coal-handling equipment or machinery.

⁹ National Fire Protection Association (NFPA). Standard 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations (2000).

¹⁰ NFPA. Standard 120: Standard for Fire Prevention and Control in Coal Mines (2004).

Coal Processing

Fire and explosion hazards generated by process operations include the accidental release of SynGas (containing carbon monoxide and hydrogen), oxygen, methanol, and ammonia. High pressure SynGas releases may cause “Jet Fires” or give rise to a Vapor Cloud Explosion (VCE), “Fireball” or “Flash Fire,” depending on the quantity of flammable material involved and the degree of confinement of the cloud. Hydrogen and carbon monoxide gases may ignite even in the absence of ignition sources if they temperatures of 500°C and 609°C, respectively. Flammable liquid spills may cause “Pool Fires.” Recommended measures to prevent and control fire and explosion risks from process operations include the following:

- Provide early release detection, such as pressure monitoring of gas and liquid conveyance systems, in addition to smoke and heat detection for fires;
- Limit potential releases by isolating process operations from large storage inventories;
- Avoid potential ignition sources (e.g., by configuring piping layouts to avoid spills over high temperature piping, equipment, and / or rotating machines);
- Control the potential effect of fires or explosions by segregating and using separation distances between process, storage, utility, and safe areas. Safe distances can be derived from specific safety analyses for the facility, and through application of internationally recognized fire safety standards;¹¹
- Limit areas that may be potentially affected by accidental releases by:
 - Defining fire zones and equipping them with a drainage system to collect and convey accidental releases of flammable liquids to a safe containment

area including secondary containment of storage tanks,

- Strengthening of buildings or installing fire / blast partition walls in areas where appropriate separation distances cannot be achieved, and
- Designing the oily sewage system to avoid propagation of fire.

1.3 Community Health and Safety

Community health and safety impacts during the construction and decommissioning of coal processing facilities are common to those of most other industrial facilities and are discussed in the **General EHS Guidelines**. The most significant community health and safety hazards associated with coal processing facilities occur during the operation phase and include the threat from major accidents related to potential fires and explosions or accidental releases of finished products during transportation outside the processing facility. Guidance for the management of these issues is presented in relevant sections of the **General EHS Guidelines** including: Hazardous Materials Management (including Major Hazards), Traffic Safety, Transport of Hazardous Materials, and Emergency Preparedness and Response. Additional relevant guidance applicable to transport by sea and rail as well as shore-based facilities can be found in the EHS Guidelines for Shipping; Railways, Ports and Harbors, and Crude Oil and Petroleum Products Terminals.

¹¹ For example, NFPA Standard 30: Flammable and Combustible Liquids Code (2003).

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1 and 2 present emission and effluent guidelines for this sector. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. These guidelines are achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document.

Emissions guidelines are applicable to process emissions. Combustion source emissions guidelines associated with steam- and power-generation activities from sources with a capacity equal to or lower than 50 MWth are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **EHS Guidelines for Thermal Power**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Affluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in the use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guideline**. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels due to specific local

project conditions should be justified in the environmental assessment.

Resource Use, Energy Consumption, Emission and Waste Generation

Table 3 provides examples of resource consumption indicators for energy and water in this sector. Table 4 provides examples of emission and waste generation indicators. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas. Relevant benchmarks for coal processing plants can be derived from coal gasification for large power plants. Emissions of gasification plants producing SynGas for Fischer-Tropsch (F-T) synthesis should be substantially lower, due to the purity requirements of synthesis catalyst.

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

Table 1. Air Emissions Levels for Coal Processing Plants

Pollutant	Unit	Guideline Value
Coal Preparation Plant		
Thermal Dryer Particulate	mg/Nm ³	70
Thermal Dryer Gas Opacity	%	20
Pneumatic Coal Cleaning Equip. Particulate	mg/Nm ³	40
Pneumatic Coal Cleaning Equip. Opacity	%	10
Conveying, Storage and Preparation Gas Opacity	%	10
Overall		
SO ₂	mg/Nm ³	150-200
NO _x	mg/Nm ³	200-400 ⁽¹⁾
Hg	mg/Nm ³	1.0
Particulate Matter	mg/Nm ³	30-50 ⁽¹⁾
VOC	mg/Nm ³	150
Total Heavy Metals	mg/Nm ³	1.5
H ₂ S	mg/Nm ³	10 ⁽²⁾
COS + CS ₂	mg/Nm ³	3
Ammonia	mg/Nm ³	30
Notes:		
1. Lower value for plants of >100 MWth equivalent; higher value for plants of <100 MWth equivalent.		
2. Emissions from Claus unit (Austria, Belgium, Germany).		
- Process emissions levels should be reviewed in consideration of utility source emissions to arrive at the lowest overall emission rate for the facility.		
- Dry gas 15% O ₂		

Table 2. Effluents Levels for Coal Processing Plants

Pollutant	Unit	Guideline Value
pH		6 - 9
BOD ₅	mg/l	30
COD	mg/l	150 (40 cooling water)
Ammoniacal nitrogen (as N)	mg/l	5
Total nitrogen	mg/l	10
Total phosphorous	mg/l	2
Sulfide	mg/l	1
Oil and grease	mg/l	10
TSS	mg/l	35
Total metals	mg/l	3
Cadmium	mg/l	0.1
Chromium (total)	mg/l	0.5
Chromium (hexavalent)	mg/l	0.1
Copper	mg/l	0.5
Cobalt	mg/l	0.5
Zinc	mg/l	1
Lead	mg/l	0.5
Iron	mg/l	3
Nickel	mg/l	1
Mercury	mg/l	0.02
Vanadium	mg/l	1
Manganese	mg/l	2
Phenol	mg/l	0.5
Cyanides	mg/l	0.5

Table 3. Resource and Energy Consumption

Parameter	Unit	Industry Benchmark
Electric Power Electric power consumption of Coal-to-Liquid plants	MWhr/ Metric Ton of total Coal-to-Liquid products	0.05 – 0.1
Electric Power consumption of methanol plants	MWhr/Metric Ton of methanol	0.07

Table 4. Emissions and Waste Generation⁽¹⁾

Parameter	Unit	Industry Benchmark
SO ₂	g/Nm ³ of SynGas	0.3 - 0.5
SO ₂ (Coal-Methanol-Gasoline) ⁽⁴⁾	tons/day	6-14
SO ₂ (Fischer-Tropsch) ⁽⁴⁾	tons/day	9-14
NO _x	g/Nm ³ of SynGas	0.35-0.6
NO _x (Coal-Methanol-Gasoline) ⁽⁴⁾	tons/day	5-15.5
NO _x (Fischer-Tropsch) ⁽⁴⁾	tons/day	5-23.6
PM10	g/Nm ³ of SynGas	0.12
Particulates (Coal-Methanol-Gasoline) ⁽⁴⁾	tons/day	0.5-7.5
Particulates (Fischer-Tropsch) ⁽⁴⁾	tons/day	1-6
CO ₂ ⁽²⁾⁽³⁾	kg/kg of coal	1.5
CO ₂ (Coal-Methanol-Gasoline and Fischer-Tropsch) ⁽⁴⁾	tons/day	21,000
Ammonia	g/Nm ³ of SynGas	0.004
Solid Waste (ash, slag and sulfur) ⁽²⁾	kg/ton of coal	50 – 200
Notes:		
1. Production: 1,300 – 1,500 Nm ³ of SynGas/t of coal		
2. According to rank and grade of coal: calculated for a GHP = 30 GJ/kg		
3. Without carbon capture and sequestration (CCS)		
4. Reference: Edgar, T.F. (1983). For a 50,000 bbl/day coal liquefaction facility		

2.2 Occupational Health and Safety Performance

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV[®]) occupational exposure guidelines and Biological Exposure Indices (BEIs[®]) published by American Conference of

Governmental Industrial Hygienists (ACGIH),¹² the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),¹³ Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),¹⁴ Indicative Occupational Exposure Limit Values published by European Union member states,¹⁵ or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)¹⁶.

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals¹⁷ as part of an occupational health and safety monitoring program.

Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

¹² Available at: <http://www.acgih.org/TLV/> and <http://www.acgih.org/store/>

¹³ Available at: <http://www.cdc.gov/niosh/npg/>

¹⁴ Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

¹⁵ Available at: http://europe.osha.eu.int/good_practice/risks/ds/oe/

¹⁶ Available at: <http://www.bls.gov/iif/> and <http://www.hse.gov.uk/statistics/index.htm>

¹⁷ Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

3.0 References and Additional Sources

Edgar, T.F. 1983. Coal Processing and Pollution Control. Houston: Gulf Publishing Company.

European Bank for Reconstruction and Development (EBRD). Sub-sectoral Environmental Guidelines: Coal Processing. London: EBRD. Available at <http://www.ebrd.com>

European Commission. 2006. European Integrated Pollution Prevention and Control Bureau (EIPPCB). Best Available Techniques (BAT) Reference Document for Large Combustion Plants. July 2006. Sevilla, Spain: EIPPCB. Available at <http://eippcb.jrc.es/pages/FActivities.htm>

European Commission. 2003. European Integrated Pollution Prevention and Control Bureau (EIPPCB). Best Available Techniques (BAT) Reference Document for Mineral Oil and Gas Refineries. February 2003. Sevilla, Spain: EIPPCB. Available at <http://eippcb.jrc.es/pages/FActivities.htm>

German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU). 2002. First General Administrative Regulation Pertaining to the Federal Emission Control Act (Technical Instructions on Air Quality Control – TA Luft). Bonn: BMU. Available at http://www.bmu.de/english/air_pollution_control/ta_luft/doc/36958.php

Intergovernmental Panel on Climate Change (IPCC). 2006. Special Report, Carbon Dioxide Capture and Storage, March 2006. Geneva: IPCC.

Kirk-Othmer, R.E. 2006. Encyclopedia of Chemical Technology. 5th Edition. New York: John Wiley and Sons Ltd.

Lockhart, N. 2002. Advances in Coal Preparation. London: World Energy Council. Available at http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/1_2_02.asp

National Fire Protection Association (NFPA). 2004. Standard 120: Standard for Fire Prevention and Control in Coal Mines. 2004 Edition. Quincy, MA: NFPA.

NFPA. 2003. Standard 30: Flammable and Combustible Liquids Code. 2003 Edition. Quincy, MA: NFPA.

NFPA. 2000. Standard 850: Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations. 2000 Edition. Quincy, MA: NFPA.

Northeast States for Coordinated Air Use Management (NESCAUM). 2003. Mercury Emissions from Coal-Fired Power Plants: The Case for Regulatory Action. October 2003. Boston, MA: NESCAUM

United States (US) Environmental Protection Agency (EPA). 2005. 40 CFR Part 60, Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units, Clean Air Mercury Rule. Washington, DC: US EPA.

US EPA. 40 CFR Part 60. Standards of Performance for New Stationary Sources. Subpart Y—Standards of Performance for Coal Preparation Plants. Washington, DC: US EPA.

US EPA. 40 CFR Part 434—Coal Mining Point Source Category BPT, BAT, BCT Limitations and New Source Performance Standards. Washington, DC: US EPA.

United States Congress. 2005. Clean Skies Act of 2005. (Inhofe, S.131 in 109th Congress). Washington, DC: Library of Congress. Available at <http://thomas.loc.gov/cgi-bin/query/z?c109:S.131>:

University of New Hampshire Recycled Materials Resource Center (RMRC). Coal Bottom Ash/Boiler Slag. Available at <http://www.rmrc.unh.edu/>

Zhu D. and Y. Zhang. Major trends of new technologies for coal mining and utilization beyond 2000 - Technical scenario of the chinese coal industry. China Coal Research Institute, Ministry of Coal Industry, Beijing, China. Available at http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/3_1_11.asp

Ullmann's Encyclopedia of Industrial Chemistry. 2005. Wiley-VCH Verlag GmbH & Co. Available at <http://www.wiley-vch.de/vch/software/ullmann/index.php?page=home>

Annex A: General Description of Industry Activities

Coal processing into gaseous or liquid chemicals, including fuels, involves the following processes and auxiliary facilities:

- Coal gasification to synthesis gas – SynGas (CO + H₂)
- Indirect liquefaction, (i.e., Fischer - Tropsch synthesis of automotive fuels (gasoline and gas oil) from SynGas)
- Ammonia from SynGas
- Methanol from SynGas
- Direct liquefaction, (e.g., coal liquefaction by direct hydrogenation)

Coal

Coal is one of the world's most plentiful energy resources, and its use is likely to increase as technologies for disposal of greenhouse gases, namely CO₂, become available. Coal occurs in a wide range of forms and qualities. The degree of conversion of plant matter or coalification is referred to as "rank". Brown coal and lignite, sub-bituminous coal, bituminous coal, and anthracite make up the rank series with increasing carbon content. The American Society for Testing and Materials (ASTM) classification is presented in Table A.1.¹⁸

Coal with less than 69 percent fixed carbon is classified according to their Gross Calorific Value (GCV):

- **Bituminous** if GCV > 24,400 kilojoules per kilogram (kJ/kg), agglomerating
- **Subbituminous** if 19,300 kJ/kg < GCV < 26,700 kJ/kg, non-agglomerating
- **Lignitic** if 14,600 kJ/kg < GCV < 19,300 kJ/kg, non-agglomerating

		Fixed Carbon ⁽¹⁾ (%)		Volatile Matter ⁽¹⁾ (%)	
		min	max	min	max
Anthracitic	Meta-anthracite	98			2
	Anthracite	92	98	2	8
	Semianthracite	86	92	8	14
Bituminous	Low volatile	78	86	14	22
	Medium volatile	69	78	22	31
	High volatile		69	31	
Notes:					
⁽¹⁾ Dry, mineral-matter-free basis					

For international trade and in the European Union, separate classification systems have been agreed upon for hard coal, brown coal, and lignite.

The impurities in coals, mainly sulfur, nitrogen, and ash, cause differences in grade. Most commercial coals contain 0.5 – 4.0 weight (wt) percent sulfur, present as sulfate, pyrite, and organic sulfur. Nitrogen content typically ranges from 0.5 – 2.0 wt percent. Because nitrogen is mostly bound to organic molecules, it is not removable physically. Coal ash is derived from the mineral content of coal upon combustion or utilization. Coal ashes may contain trace elements of arsenic, beryllium, cadmium, chromium, copper, fluorine, lead, manganese, and mercury.

Coal Gasification

Coal gasification plants widely differ in size according to the final destination of the produced SynGas. In chemical manufacturing, typical design capacity is based on a feed rate of 1,500-2,000 tons per day (t/d) of coal. Larger capacities are possible, especially for methanol production. In the case of liquid fuel manufacturing, existing facilities use 120,000 t/d (ca. 40

¹⁸ Kirk-Othmer, Encyclopedia of Chemical Technology, 5th Edition (2006).

megatons per year (Mt/y)) of coal to produce 160,000 barrels per day (bbl/d) (ca. 10 Mt/y) oil equivalents of liquid fuel.

Coal Logistics and Preparation

Large coal-to-oil plants are typically located near coal mines, and share storage areas and facilities. The coal is typically fed to plant bins, bunkers, and hoppers by conveyor belts. Smaller plants may be located far from mines. In this case, coal is transported by railway, barge, or slurry pipeline and is stored in stockpiles. Typically, preparation of coal is necessary prior to shipping and use, depending on the mine and coal characteristics as well as the mining technology.¹⁹ Coal preparation is discussed in the **EHS Guidelines for Mining**. Prior to utilization, coal stored in the coal processing facilities is converted into the physical forms needed by the SynGas production reactor, which differ based on SynGas production technology. Typical operations include coal drying and size reduction (crushing, grinding, or pulverization).

SynGas Production Facilities

Coal gasification involves the reaction of coal with oxygen, steam, and carbon dioxide to form a product gas (SynGas) containing hydrogen and carbon monoxide. Essentially, gasification involves incomplete combustion in a reducing environment. The main operating difference compared to complete coal combustion is that gasification consumes heat produced during combustion. Under the reducing environment of gasification, sulfur in the coal is released as hydrogen sulfide rather than as sulfur dioxide, and nitrogen in coal is converted mostly to ammonia rather than nitrogen oxides. These reduced forms of sulfur and nitrogen are easily isolated, captured, and utilized.

Depending on the type of gasifier and the operating conditions, gasification can be used to produce a SynGas suitable for any number of applications. A simplified version of the gasification process is outlined in Figure A.1.

Prepared coal is fed to gasification, together with oxygen and steam. Depending on the specific type of gasifier, SynGas flowing out from the reactor may be quenched and cooled and the heat recovered as high pressure steam. Ash is recovered from the bottom of the reactor, together with tar, either solid or slagged (depending on the process). SynGas is blended with steam and fed to the shift reactor to adjust the H₂/CO ratio to the required value. SynGas is later purified of H₂S, CO₂, COS, NH₃, HCN to the required specifications. Three main types of gasification reactors are used: fixed-bed reactors, fluidized-bed reactors, and entrained-flow reactors.

Fixed-Bed Reactors

Countercurrent, fixed-bed gasifiers were among the earlier types of reactors to be developed. In this process, air and steam are introduced at the bottom and travel upward through a coal bed. Coal is fed onto the top of the bed and travels downward countercurrent to the flow of gases. Fixed beds have several advantages. The flow of the hot gases up from the combustion zone preheats the coal leading to heating efficiency gains. High carbon conversion is achieved by plug flow of solids through the gasification and combustion zones, and the relatively long residence times of the fuel in the reactor. The product gas exits at relatively low temperatures and without contamination of solids. However, oil and tar may be present, and may cause fouling of downstream equipment.

The disadvantage of the fixed-bed gasifiers is the inability to process caking (agglomerating) coals (e.g., bituminous coal rank), which have a tendency to swell and agglomerate upon

¹⁹ Lockhart, N., World Energy Council. *Advances in Coal Preparation* (2002).

heating. These coals may disrupt gas and solid flows, leading to process failure.

Fluidized-Bed Reactors

Fluidized-bed gasifiers enable improved mixing and uniformity of temperatures, allowing oxygen to react with the devolatilization products. In dry fluidized-bed gasifiers, temperatures have to be maintained below the ash melting point, causing incomplete carbon conversion for unreactive coals. Agglomerating ash gasifiers operate at higher temperatures (up to 1,150 °C), near the ash softening point, allowing improved carbon conversion and gasification of unreactive high rank coals and caking coals. The higher temperatures increase gasification rates, coal output and efficiency. The primary advantage of fluid-bed gasifiers is the flexibility to use caking coals, as well as low quality coals of high ash content. In addition, a fluid-bed gasifier is able to operate over a wide range of operating loads or outputs without significant drop in process efficiency.

Entrained-Flow Reactors

In this type of reactor, gasifiers may be dry-feed, pressurized, oxygen-blown, entrained-flow slagging type. The coal is dried and pulverized to particle diameter < 0.1 mm, prior to being fed into the gasifier with a transport gas, generally nitrogen. Coal, oxygen, and steam enter the gasifier through horizontally opposed burners. Raw fuel gas is produced from high-temperature gasification reactions and flows upwardly, with some entrained particulates composed of ash and a small quantity of unreacted carbon.

The high reactor temperature converts the remaining ash into a molten slag, which flows down the walls of the gasifier and passes into a slag quench bath. The raw fuel gas can be quenched at the reactor exit with cooled recycled fuel gas to lower the temperature below the melting point of the ash, and

avoid sticky solids entering the raw fuel gas cooler. The raw gas cooler further cools the gas and generates high-pressure steam which is sent to the steam cycle. Solids are recovered in the particulate filters and recycled back to the reactor. This type of reactor can easily manage coal of all ranks.

Indirect Coal Liquefaction

Liquid Hydrocarbon Production

F-T processes can be used to produce a light synthetic crude oil (syncrude) and light olefins, or heavy waxy hydrocarbons. Syncrude can be refined to gasoline and gas oil, and the heavy hydrocarbons to specialty waxes or, if hydrocracked and / or isomerized, used to produce gas oil, lube oils, and naphtha, which is a feedstock for cracking to olefins. Iron-based catalysts promoted with potassium and copper are used.

Typical reactor designs for F-T reaction include low-temperature reactors (LTFT, slurry-bed reactors) and high-temperature reactors (HTFT, fluid-bed reactors).

The **slurry-bed reactors** consist of a vessel containing a slurry of process-derived wax including a catalyst. SynGas is bubbled through the slurry bed at typical process conditions of 220–250 °C and 2.5–4.5 megapascals (MPa), and is converted to hydrocarbons. The heat generated is passed from the slurry to the cooling coils inside the reactor to generate steam. The light hydrocarbons, which are in the vapor phase, are removed from the freeboard at the top of the reactor with the unconverted reactants and are condensed in the downstream condensing train. The heavier liquid hydrocarbons are mixed into the slurry from which they are removed in a solid separation process.

The **fluid-bed reactors** consist of a vessel containing a fluidized bed of fused and reduced iron catalyst. SynGas is bubbled by means of a gas distributor through the bed where it is catalytically converted to hydrocarbons which, at the process

conditions of about 340 °C and 2.5 MPa, are in the vapor phase. The products and unconverted gases leave the reactor through internal cyclones.

Alkylation

The purpose of alkylation is to yield high-quality motor fuel. The term alkylation is used to describe the reaction of olefins with isobutane, to form higher molecular-weight isoparaffins with a high octane number. The process involves low-temperature reaction conditions conducted in the presence of strong acids (hydrofluoric acid (HF) or sulphuric acid (H₂SO₄)).

Isomerization

Isomerization is used to alter the arrangement of a molecule without altering the composition of the original molecule. Low molecular weight paraffins (C₅ – C₆) are converted to isoparaffins, which have a much higher octane index. Three distinct types of catalysts are currently used for this process: chloride promoted alumina, zeolitic, and sulphated zirconia.

Catalytic Cracking

Catalytic cracking is used for upgrading heavier hydrocarbons into more valuable, lower boiling hydrocarbons. The process uses heat and a catalyst to break larger hydrocarbon molecules into smaller, lighter molecules. Fluid catalytic cracking (FCC) units are commonly used consisting of three distinct sections: a reactor-regenerator section including air blower and waste heat boiler; the main fractionator section including a wet gas compressor; and the unsaturated gas plant section. In the FCC process, oil and oil vapor preheated to 250 to 425 °C is contacted with hot catalyst (zeolite) at about 680–730 °C in the riser reactor. To enhance vaporization and subsequent cracking, the feed is atomized with steam. The cracking process takes place at temperatures between 500 and 540 °C and a pressure of 1.5-2.0 barg. Most catalysts used in catalytic cracking are

zeolites supported by amorphous synthetic silica-alumina with metals.

Oxygenate Hydrogenation

In this process, oxygenate compounds are hydrogenated to an alcohol mixture.

Ammonia Production

Ammonia (NH₃) production plants may be stand-alone units or integrated with other plants, typically with urea and methanol production. Hydrogen and / or carbon monoxide production can also be integrated with ammonia plants. Ammonia is produced by an exothermic reaction of hydrogen and nitrogen. This reaction is carried out in the presence of metal oxide catalysts at elevated pressure. The raw material source of nitrogen is atmospheric air and it may be used in its natural state as compressed air or as pure nitrogen from an air separation unit. Hydrogen is available from a variety of sources such as natural gas, crude oil, naphtha, or off gases from coal processing.

Ammonia production from SynGas includes the following process steps: removal of trace quantities of sulfur in the feedstock; primary and secondary reforming; carbon monoxide shift conversion; removal of carbon dioxide; methanation; compression; ammonia synthesis; and ammonia product refrigeration. Carbon is removed in the form of concentrated carbon dioxide (CO₂), which may be used for urea manufacture or other industrial purposes to avoid release to the atmosphere. Catalysts used in the process may contain cobalt, molybdenum, nickel, iron oxide / chromium oxide, copper oxide / zinc oxide, and iron.

Two non-conventional process routes include: the addition of extra process air to the secondary reformer with cryogenic removal of the excess nitrogen; and heat-exchange autothermal reforming. The latter process route has some environmental

advantage given the reduced need for firing in the primary reformer and the potential for lower energy consumption.

Methanol Production

The methanol synthesis unit typically involves reaction, gas recycling, and purification. In the reaction, carbon monoxide and hydrogen react at about 250°C and 50-80 bar in the presence of a copper-based catalyst to yield methanol. Commercially available reactors include fixed bed tubular or multi-beds adiabatic radial types. Down-stream of the reactor, methanol is condensed and the unconverted gas is recycled to the SynGas production unit. The purification section involves two fractionation towers where both light-ends and heavy-ends (high molecular weight alcohols) are removed from methanol product. Light-ends are typically recovered as fuel gas. Heavy-ends are typically burned in a steam boiler through a dedicated burner.

Direct Coal Liquefaction

Many countries have undertaken research and development into direct coal liquefaction. Most processes under development are based on catalytic hydrogenation of coal dispersed and partially dissolved in an organic solvent. The reaction is strongly dependent on the rank, the grade, and the ageing of coal. For low rank coals, blends of water, hydrogen and CO (SynGas) are more effective hydrogenation agents. Catalyst poisoning by coal impurities is a problem, along with waste water treatment. Large pilot plants and demonstration plants have been successfully operated.

Figure A.1: Block Flow Diagram of Coal Gasification

