Driving Change:
The Role of Specialty Coke in the Energy Transition

Al A. Faegh, Delayed Coking Technology Director
Hydrocarbon Engineering, Tuesday, December 5, 2023

Chevron Lummus Global

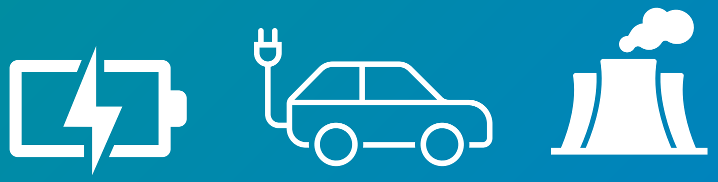
Energy Transition – A New Playing Field

Energy Transition: *Defined as a shift away from fossil fuel sources of energy production and consumption*

Pathways to Achieve the Transition:

- Switching to sources of energy with zero or low emissions to produce electricity
- Electrification and its penetration into all aspects of human activities
- Increasing energy efficiency measures across the board

- Electrification of transport systems in the form of electric vehicles (Evs) and hybrid electrical vehicles (HEVs), which is already underway
- Simultaneously, there is an ever-increasing scrutiny to reduce greenhouse gas emission (GHE) of existing processes to limit CO2 emission through regulatory measures in parts of the world
- The steel industry is a major contributor to GHE through blast and basic oxygen furnaces
- The playing field has certainly been transformed

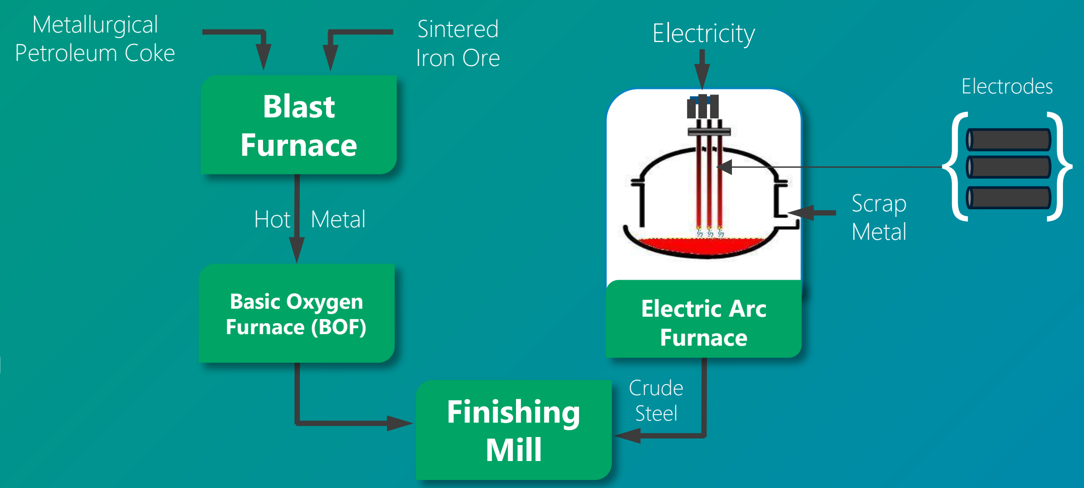


Market Review –Background

Routes of Steel Production:

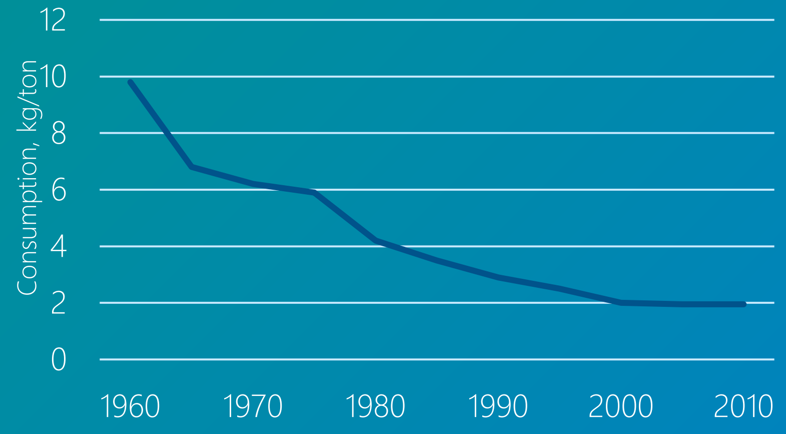
- *Basic Oxygen Furnaces/Blast Furnaces (BOF/BF) – Iron ore*
- *Electric arc furnaces (EAF) – scrap metal*

Major Routes of Steel Production



- CO_2 from BOF/BF is five times more than EAF steel production
- EAFs use electrodes to generate the arc for melting scraps
- Needle coke is the primary ingredient for the production of electrodes used in EAF
- Last century's supply of needle coke was in balance with demand due to:
  - *Lower steel demand*
  - *Improvement in the EAF technology that dropped the electrode >9 kg/ton of steel to 2.5 kg/ton of steel*

Electrode Consumption



Market Review – Shifting Supply/Demand

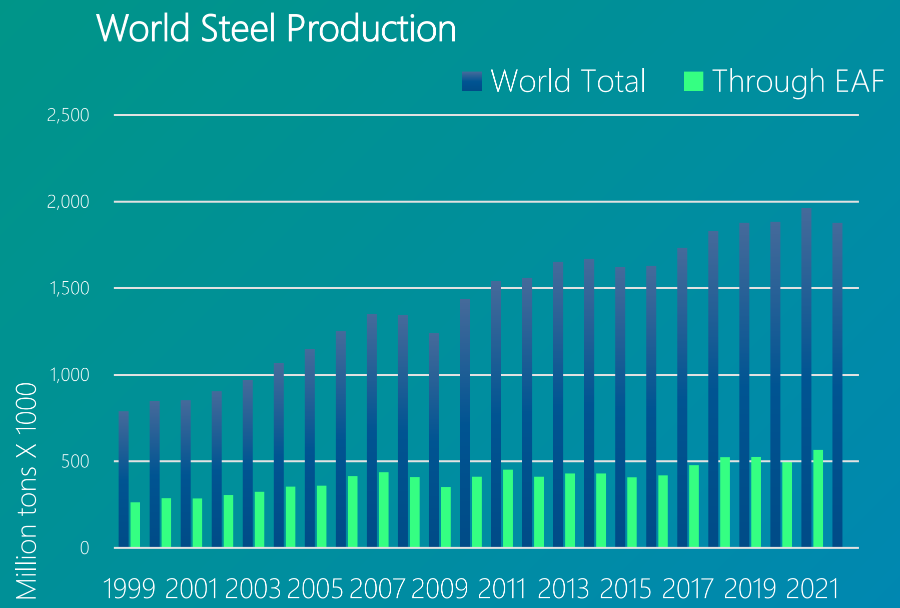
Chevron Lummus Global

Steel production via EAF started to increase due to an increase in steel demand/production since the start of the 21st century

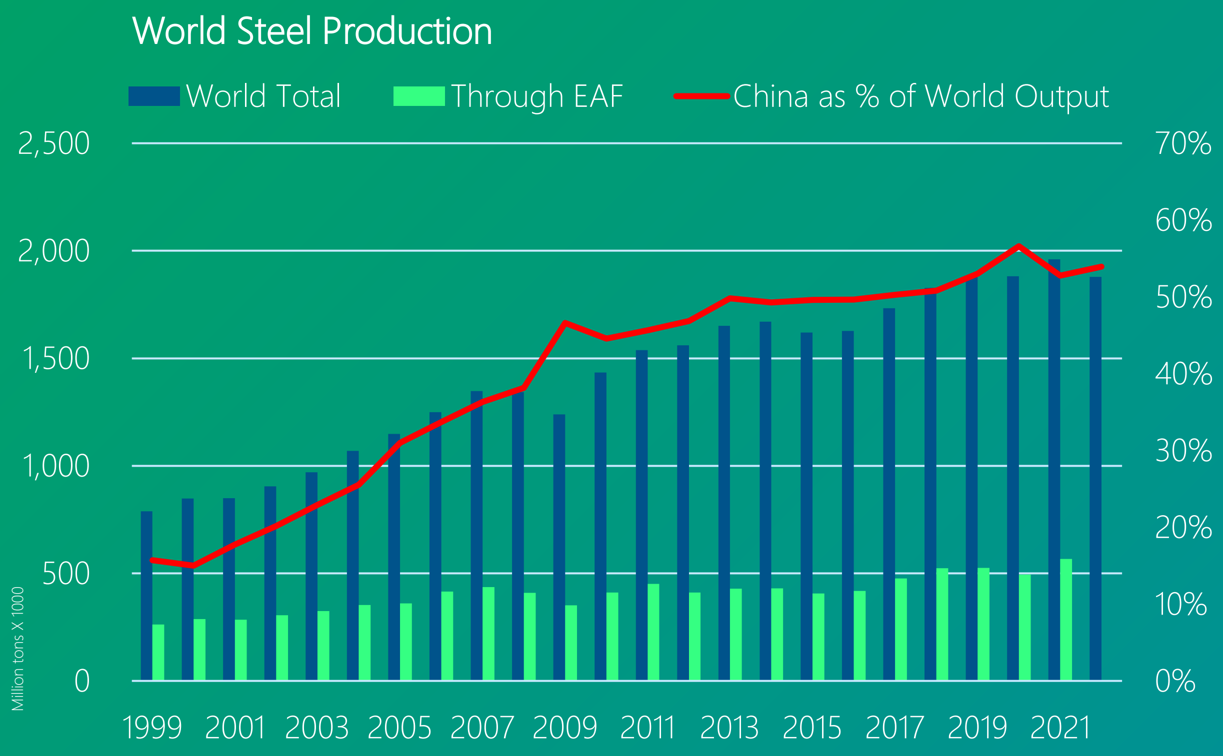
- Average steel production rose by 44% since 2000
- Steel produced by EAF rose by 82%
- Therefore, the demand for electrodes increased

A tight needle coke supply and demand market emerged

- Small change on the demand or supply side led to sharp increase in the price of needle coke:
  - 2003 to 2007 due to sharp steel demand
  - Hurricane Harvey affecting needle coke plants on the Gulf Coast
  - Closure of six electrode manufacturing facilities in China in 2017



Market Review – Shifting Supply/Demand



The tight market was also responsible for a sharp drop in needle coke price because of a decrease in steel demand

Examples are the economic slowdown in 2008 –2009

China's economic slowdown in 2015 and oversupply of the world market with steel

It is worth noting that China is both a major producer and consumer of steel. Even during the 2022 slowdown, their steel production made up over 50% of world steel production

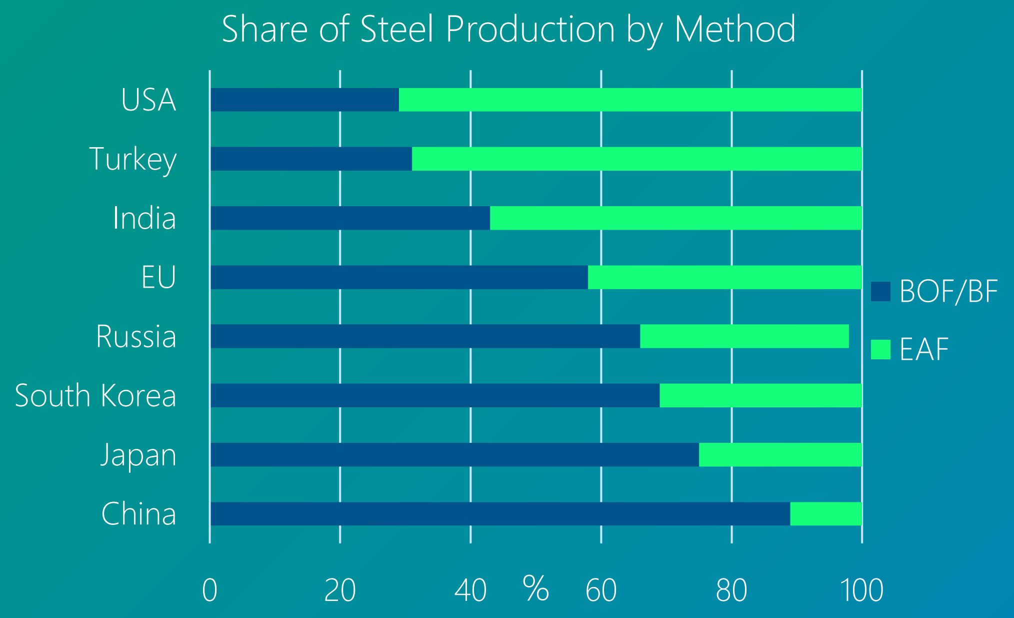
Market Review – Market Drivers for Needle Coke

Chevron Lummus Global

- **Production through EAFs will increase. The factors responsible are:**
  - Increase in steel demand/production – despite the devastating impact of COVID-19, 2020 and 2021 saw an increase in steel production
  - China is targeting major emitters as part of the effort toward a carbon-neutral future by increasing the share of steel produced by EAF
  - India as the third largest producer of steel, is also planning to increase steel production to 300 million metric tons by 2030 per National Steel Policy 2017. This is part of the country's attempt to increase its per capita steel consumption from 80 to 160 kilograms by 2030-31
- **These forecasts regarding China are dependent on the economy of that country.**
  - The zero COVID policy held back their forward surge after COVID

Market Review – Market Drivers for Needle Coke

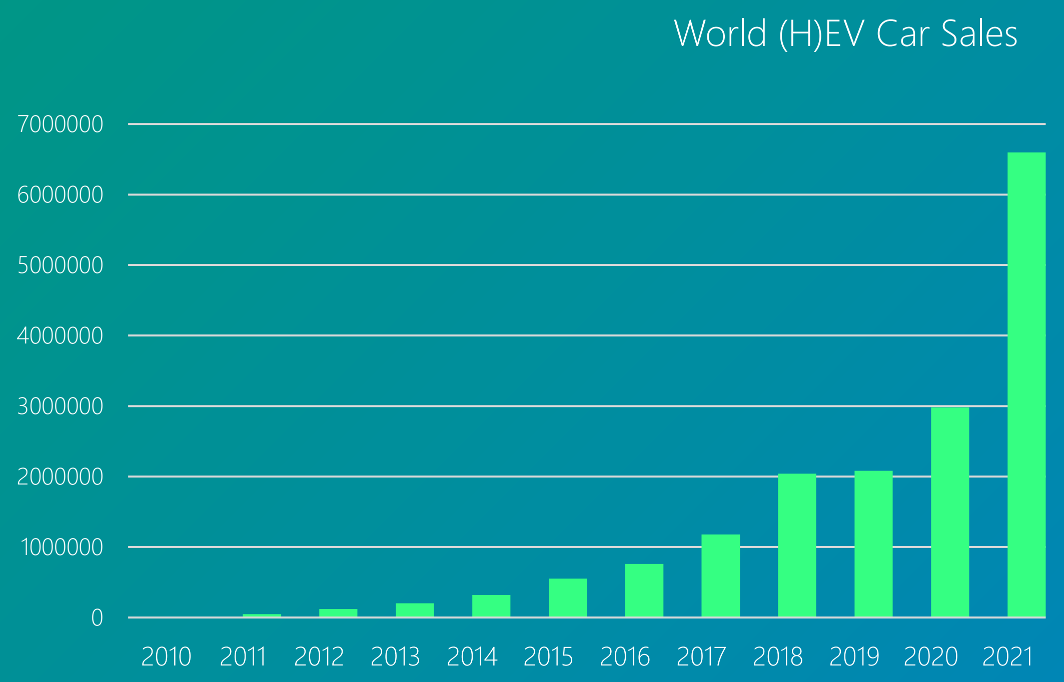
- **Putting the shift to EAF in China and India in perspective:**
  - China's steel production through EAF is ~11%
  - An increase of 9% is equivalent to 95 million MT of EAF steel-based on China's 2020 total steel production
  - This additional production through EAF is equivalent to more than the total production of Europe by EAF
  - It is not likely that China will be able to implement this level of increase due to limitations on the availability of good-quality scraps
  - However, even a small increase will reverberate around the global market



- **Other countries also will take steps to lower emission**

Market Review – Newcomer

- Sales of electric and hybrid vehicles or (H)EVs soared since 2010
- Multiple reasons for this surge and sustained growth:
  - Regulatory policies by governments to reduce CO2 emissions
  - Extension to other car models and markets, such as public transportation and the trucking industry
  - Reduction in the cost of batteries
  - Growing consumer support
- IEA forecasts that the global electric car stock will expand to ~350 million vehicles by 2030
  - Growth is dependent on the supply of critical minerals
  - There were 16.5 million H(EVs) the end of 2021

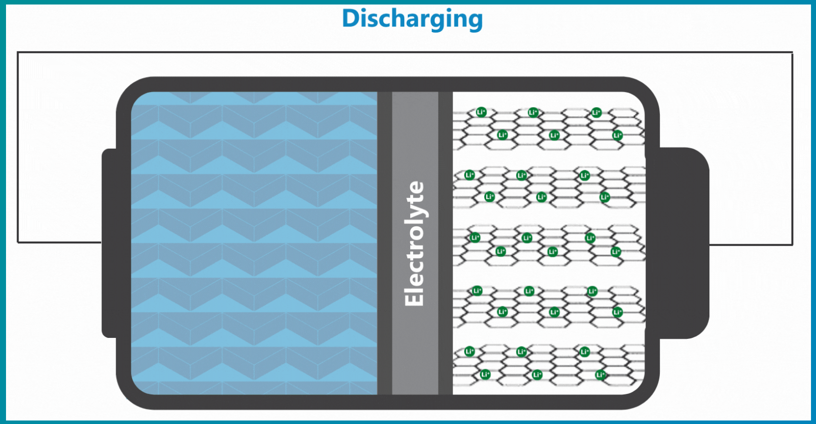


Market Review – Anatomy of Lithium-ion Batteries (LIB)

Chevron Lummus Global

LIBs are Basically Rechargeable Batteries

- Lithium has a high electrochemical potential that can provide the required energy density
- Basic battery structure: cathode, anode and electrolyte to allow the ion to move in between, and a separator
- The process, in simple terms, consists of the lithium-ion shuttling back and forth between the anode and cathode
- Lithium ion moves from the cathode and takes residence in the interlayer space of the graphite
- The reverse happens during the discharge
- This process is called intercalation of the lithium-ion



Market Review – Graphite

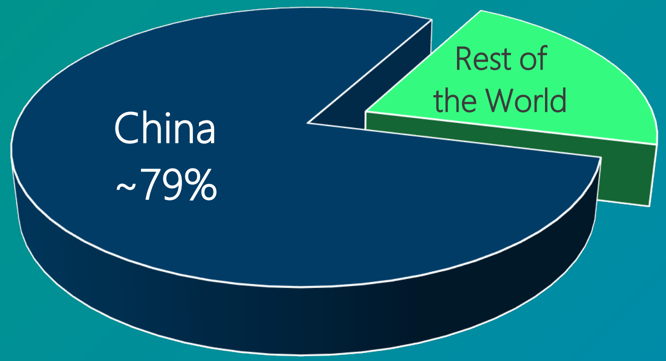
Natural and synthetic graphite continue to dominate as primary anode materials for lithium-ion batteries (LIBs)

- 10 to 15 times more graphite in LIBs than lithium
- ~ 10 kilograms of graphite used in HEVs and seven times more in EVs
- Preferred source is natural graphite – easily available for now
- Also, synthetic graphite with similar qualities as needle coke is used
- Current market share between the two is ~50/50

The total world production of natural graphite for 2022 is estimated by the U.S. Geological Survey (USGS) to be 1.3 million tons

- China is a dominant producer, followed by Brazil and Mozambique
- This imbalance will put the supply at risk. That is why USGS considers graphite to be a critical and strategic mineral
- IEA estimates the demand for graphite to grow by 10 to 25 times the 2020 demand depending on growth scenarios

Share of Graphite Mine Production



Source: US Geological Survey, Mineral Commodity Summaries, January 2022

Market Review – Needle Coke Demand

Chevron Lummus Global

Graphite electrode demand for the production of steel is expected to increase due to:

- Increase in steel consumption
- Regulatory pressures to reduce/minimize GHE from traditional methods of steel production

Synthetic graphite as a substitute will take on a more prominent role due to:

- Electrification
- Supply risk associated with natural graphite
  - Wood Mackenzie estimates the share of synthetic graphite to reach 70% by 2030 in LIBs

These two drivers will not only stabilize the price of needle coke but can fuel high prices due to the inability to satisfy the demand

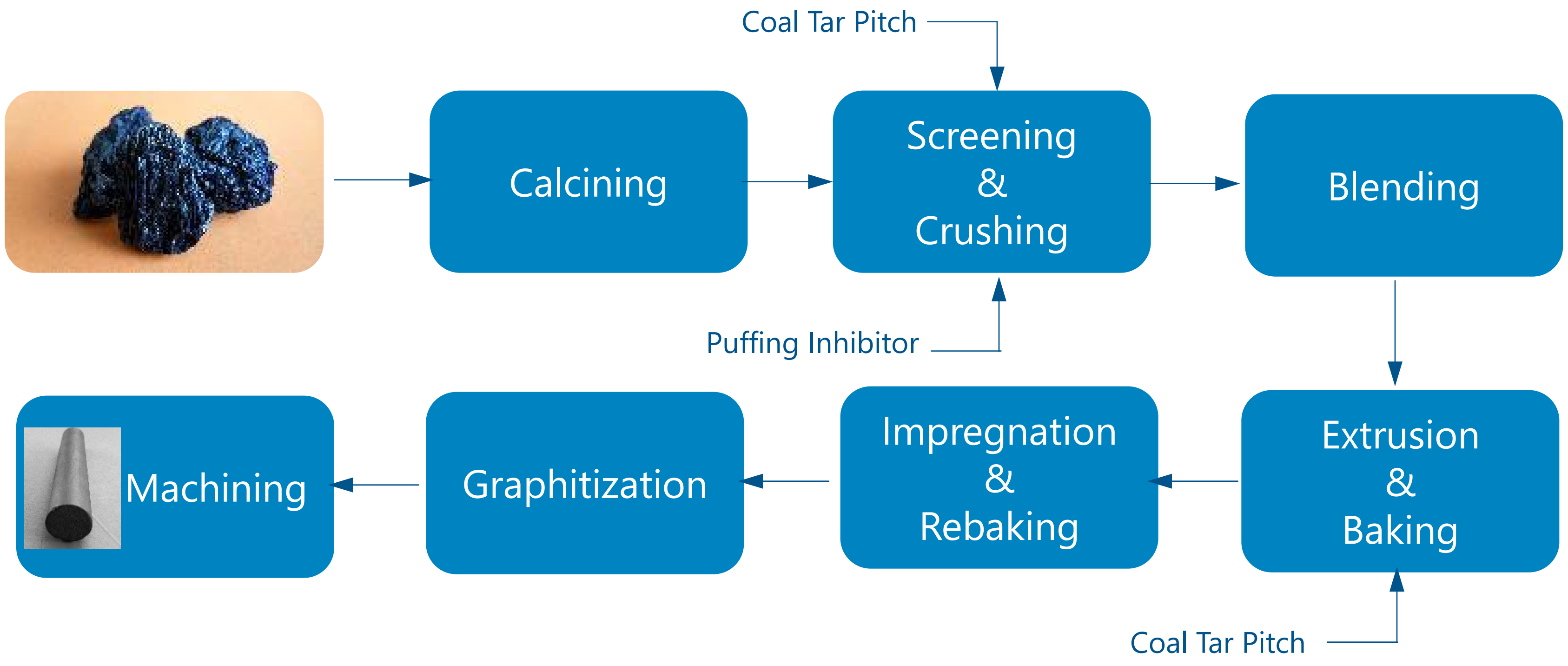
- That is what CLG is experiencing in terms of global interest in either repurposing of existing coking units or installation of new plants

Graphite Electrode Manufacturing Process

Chevron Lummus Global

The main building block of electrodes is needle coke

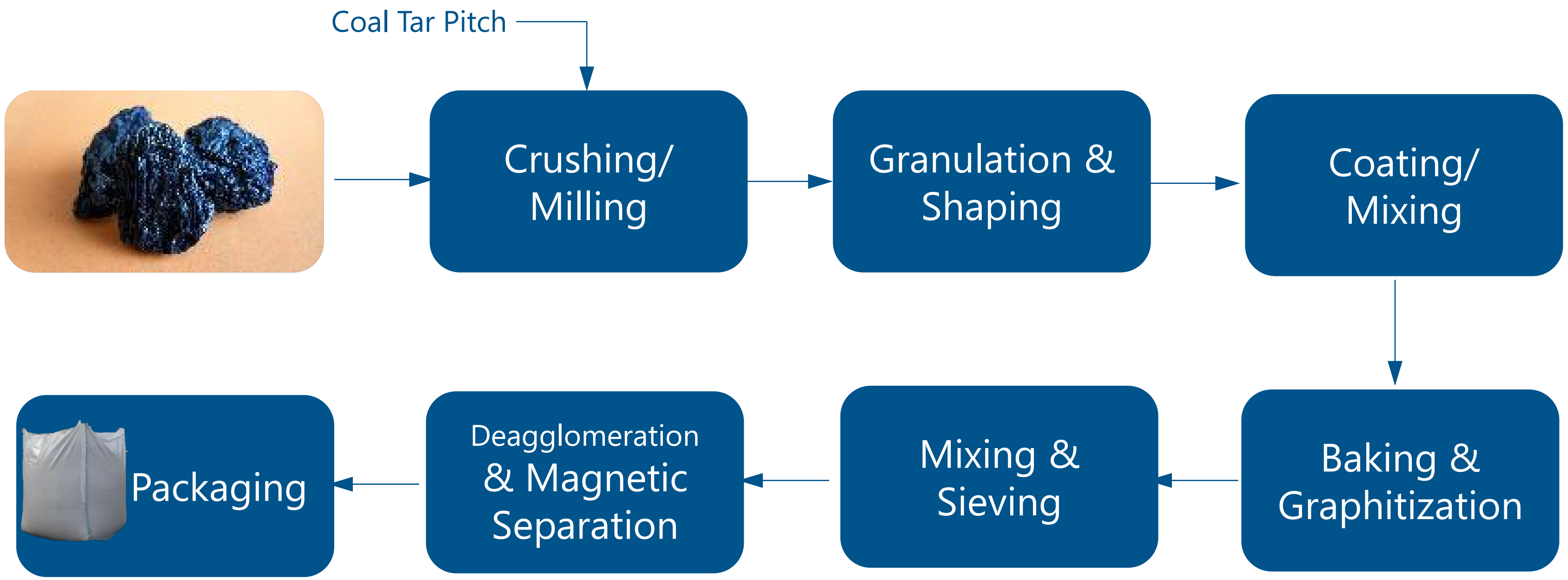
- Performance gauged long after coke is produced – longer than six months



Therefore, this type of coke is not just a specification product but a performance product

Anode Manufacturing Process

Main building block of synthetic graphite production



Graphite Electrode Quality Requirements

Low Coefficient of Thermal Expansion:

- Electrodes are exposed to high-temperature differential, > 2000^{o}C

Low Electrical Resistivity:

- High current required to generate the arc

High Mechanical Strength:

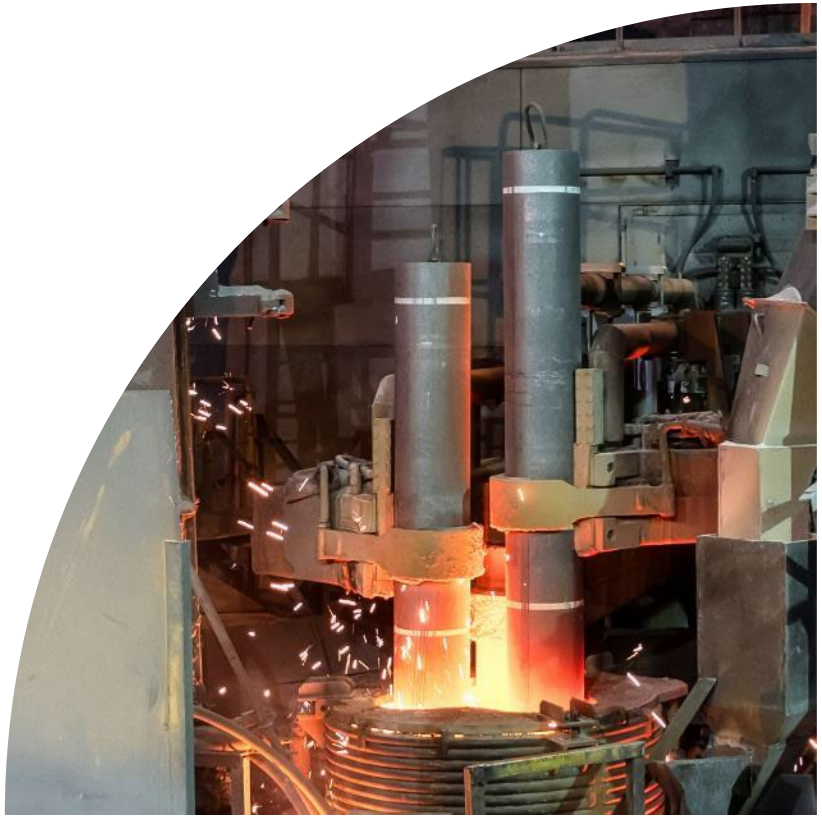
- Withstand the thermo-mechanical and electromagnetic shocks

Low Sulfur and Nitrogen to Prevent Puffing

- Puffing is the volatilization of sulfur and nitrogen that leads to electrode micro and macro cracks, compromising its integrity

Pilot Testing is Essential to Evaluate Performance

- Preparation of pilot test electrodes



Synthetic Graphite Quality Requirements

Chevron Lummus Global

Shaping and Pressing:

- Leads to higher density: more graphite on the foil; more energy

Graphitizable:

- Graphitization leads to structural order for ease of intercalation.

Crystallite Size:

- Important for ease of lithium-ion diffusion

Low Sulfur and Ash

- To reduce emissions. Lower impurity helps with crystallite size

Specific Surface Area

- Generally, to be minimized, affects the lifetime of the battery

Pilot Testing/Preparation of Coin Cell for Performance Evaluation

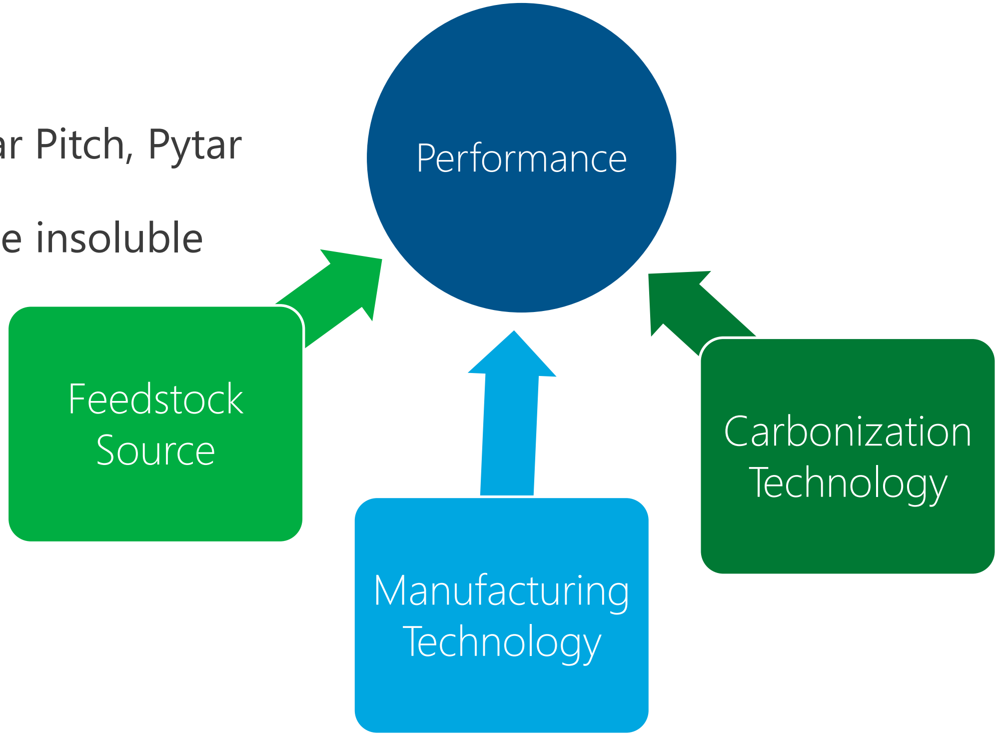
Elements Affecting Performance

Three factors play an essential role in deciding:

- Electrode performance inside the EAFs and suitability for power storage applications

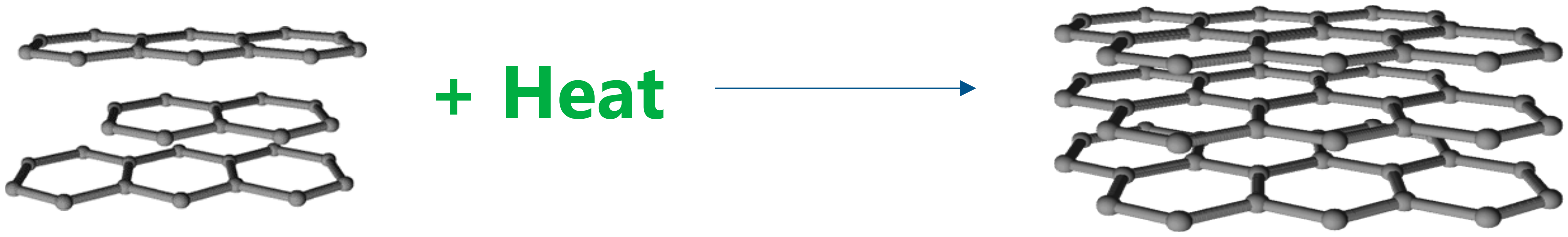
Facility Owner/Operator has an influence on two factors:

- Feedstock source
  - Highly aromatic feedstocks such as FCC Decanted Oil, Coal Tar Pitch, Pytar
  - Low in sulfur, nitrogen, asphaltenes, metals, ash, and quinoline insoluble
- Carbonization technology:
  - Conventional delayed coking
  - CLG's proprietary Two-step coking process



Carbonization Condition

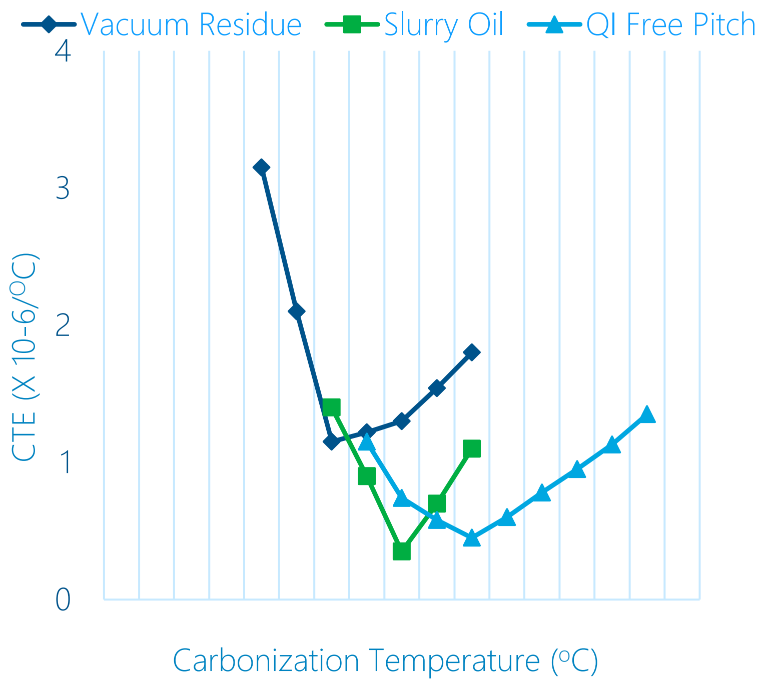
- In delayed coking, energy is needed to ultimately covert the feedstock to solid coke
- Long-range structured order is required to satisfy performance qualities needed both in graphite electrodes and lithium-ion batteries
- Reaction goes through a phase that is neither a solid nor a liquid called mesophase
- The onset of reaction is marked by appearance of meso-spheres that coalesce to eventually develop into bulk mesophase
- The process requires:
  - Adequate residence time
  - Controlled rate of reaction by the staged introduction of energy



Carbonization Condition – Optimized Temperature

Heater Coil Outlet Temperature:

- High-temperature → rapid reaction rate → disorderly fusion and alignment of mesophase rapid molecular weight growth and premature precipitation → loss of well-defined structure
- A minimum temperature is required for the generation of free radicals to allow combination of polyaromatics and appearance of meso-spheres for growth of mesophase
- It is also known that an optimum temperature range exists for which the coefficient of thermal expansion (CTE) is minimized
  - This optimum range is almost always not high enough to transition the bulk mesophase to the solid phase
  - Therefore, additional energy input (heating) will be required



Carbonization Condition – Other Parameters

Chevron Lummus Global

Coke Drum Outlet Pressure:

- Higher pressure → traps lower MW aromatics → reduces reaction mixture viscosity allowing easier coalescence of mesophase → leading to formation of larger grains
- Increases the coke yield and sets the condition for gas evolution to produce the flow domain
- Known to have a positive impact in lowering the CTE

Reaction Time:

- Increase in RXN time → allows coalescence of the meso-spheres to the bulk mesophase → better orientation of needle structure

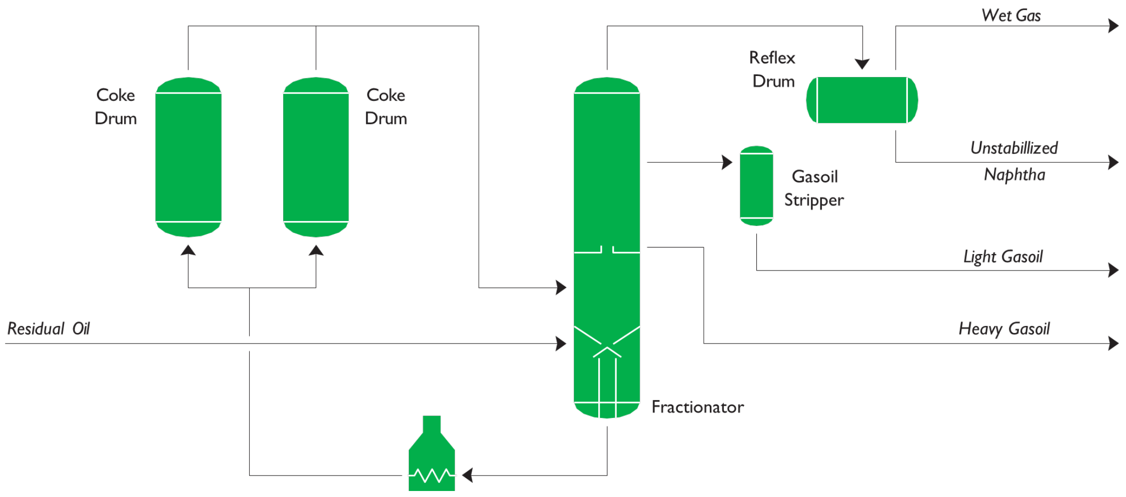
Recycle Rate:

- Returns heavy aromatic back into the coke drum for increased coke yield
- Reduces viscosity of the reaction mixture for easier coalescence of the meso-spheres

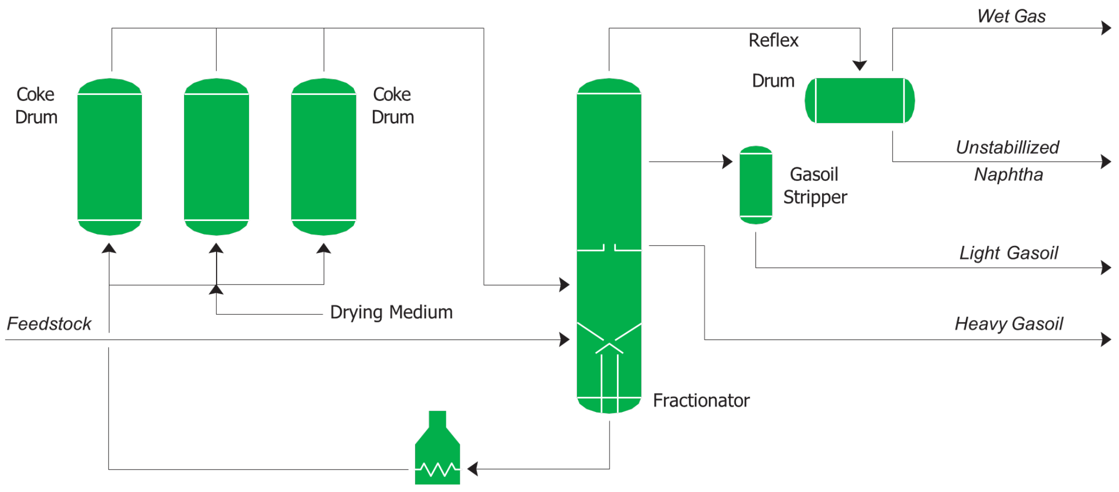
CLG's Two Step Process

Chevron Lummus Global

Conventional Process



Two Step Process



CLG Offers both processes for the production of needle coke, Carbon Precursor depending on the feedstock quality and end-use

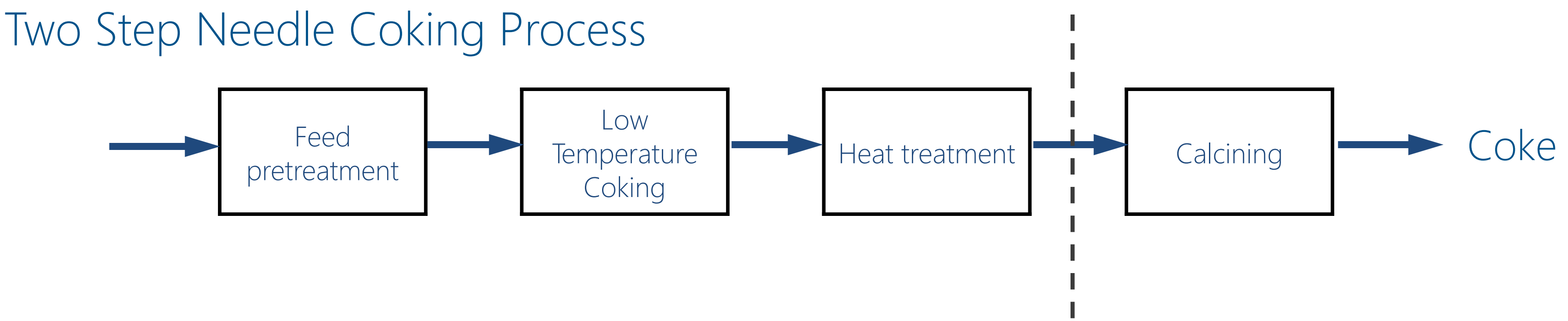
Both methods of production are used in CLG licensed units currently in operation

CLG's Two Step Process

Proprietary Technology with Unique Features:

- Coking step at low temperature – formation of free radicals and coalescence of mesophase
- Allows temperature adjustment in the coking step based on feedstock quality variation
- Drying/curing step – introduction of additional energy (heat) in a controlled fashion to build the required crystalline structure and transition to solid phase

Captures the requirements for gradual development of mesophase followed by the formation of bulk mesophase and transition to the solid phase

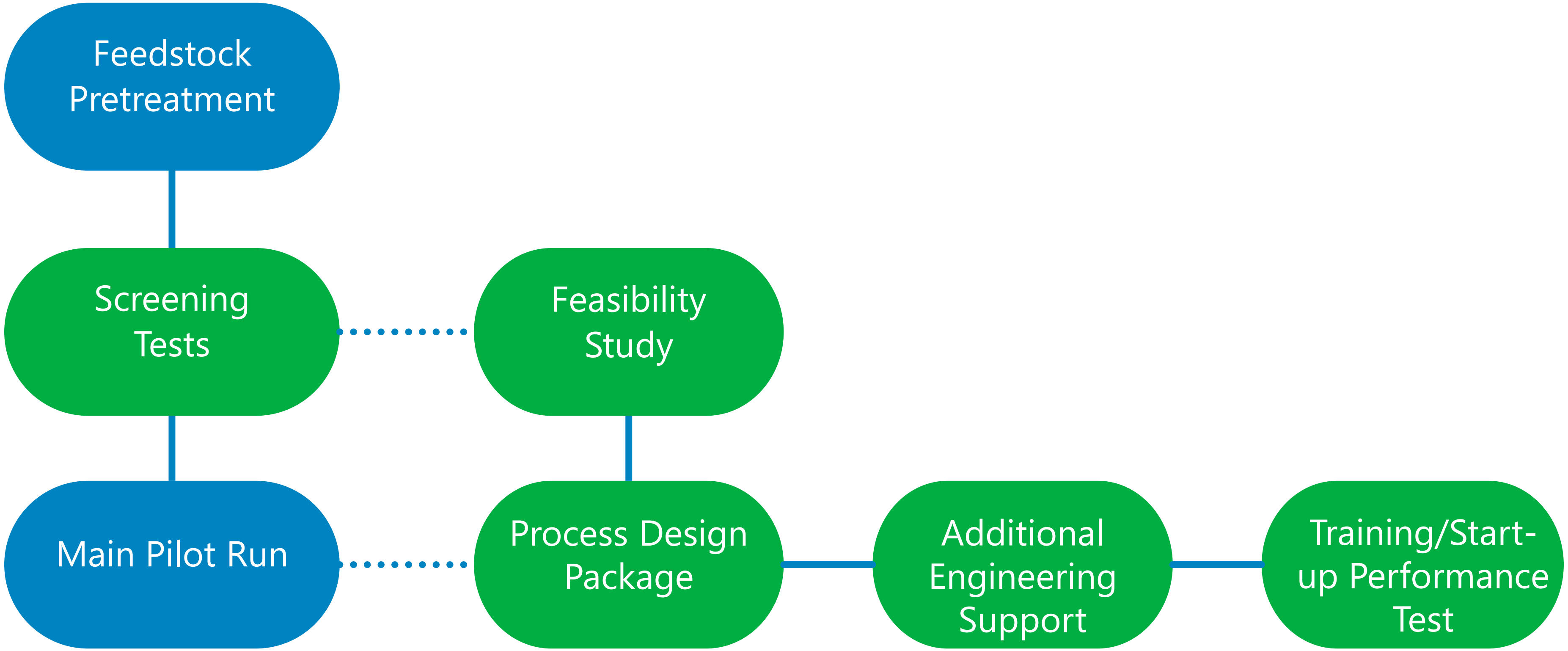


The two step process provides all the handles for the owner/operator to change the processing recipe for the production of the highest quality needle coke with minimum of CTE

Revamp and Grassroots

Typical Structure of Work:

In general, the same route is taken with minor additional steps to either re-purpose an existing unit or design a grassroots facility



Feedstock Evaluation – Pilot Testing

Chevron Lummus Global

Performance Evaluation

- Feedstock evaluation is the first step for the design or repurposing of a unit.
- Pilot testing is necessary to manufacture test electrodes for needle coke application and to prepare coin cell for testing of carbon precursor as anode material for power storage

CLG Pilot Testing Capabilities

- Filtration – to remove catalyst fines
- Main Coker pilot plant-3 and 6-inch coke drums with recycle capability that operates round the clock simulating the actual commercial unit residence time
- Mini-coker with 1 and 1½-inch coke drums
- Hydrotreatment to reduce sulfur via CLG pilot facility in Richmond, California
- Solvent De-asphalting
- Quinoline insoluble removal
- Carbon test facilities for the manufacture of test electrodes and preparation of coin cell

Q&A

Al A. Faegh, Delayed Coking Technology Director
Hydrocarbon Engineering Webinar
December 5, 2023

Chevron Lummus Global