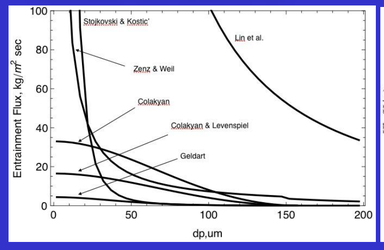
Fluidization’s Role in the Scale-Up and Commercialization of Sustainability and Decarbonization Technologies

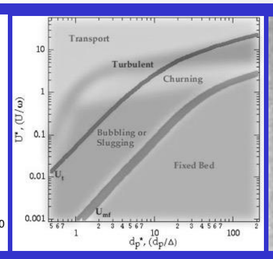
S.B. Reddy Karri

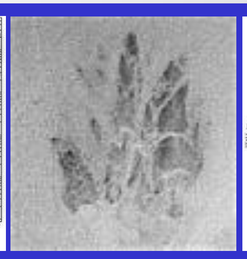
June 20, 2024

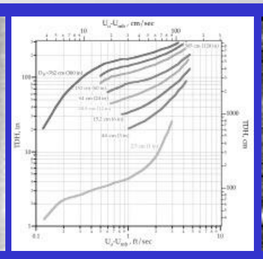
PSRI Particulate Solid Research, Inc.

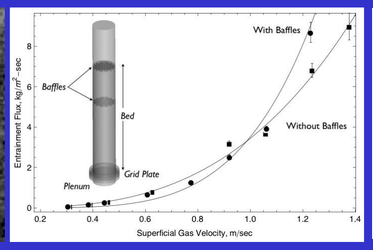
Applying the Fundamentals

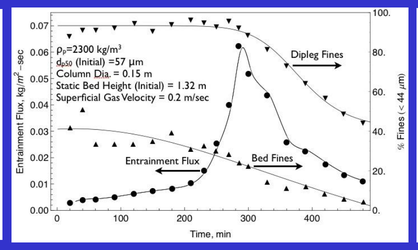


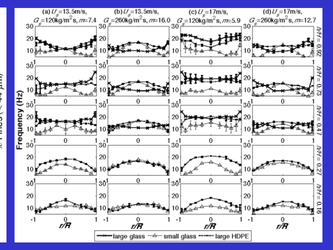












PSRI Mission and Vision

- Mission
  - PSRI is a world-class, not-for-profit organization dedicated to the education, consultation, design, optimization, research, and development of particle technology as applied to industrial processes for all its member companies
- Vision
  - PSRI will be the “first choice” for companies interested in applying particle technology concepts on the path to commercialization. **Go to place** for emerging technologies

What We Provide

PSRI has 370 cumulative years of expertise in particle technology and multiphase flow

PSRI started in 1971 and has massed 60 TB of data

PSRI consulting team all have at least 22 years of experience and success in particle technology

RI is world renowned for its expertise in fluidization

PSRI has state of the art facility designed for large-scale multiphase flow experiments

PSRI has some of the worlds most noted modelers in fluidization

If we don't know it, we have the tools to figure it out

PSRI is driven to your success which can only be realized long term with the right kind of training

PSRI has trained over 6600 s in particle technology

Membership and Contract R&D

Your Instructor

Dr. S.B. Reddy Karri, President & CEO: Reddy has 36 years experience in particle technology and fluidization. He is the President & CEO of Particulate Solid Research, Inc., an engineering industrial consortium of 36 member companies from Asia, Americas and Europe. He is an expert in the area of fluid-particle systems such as fluid beds, cyclones, diplegs, standpipes and risers. He extensively consults and trouble shoots the industrial problems in the energy filed. He currently involved in developing fifteen different emerging technologies at various stages of commercialization. He lead numerous cold flow projects relating to fluid-catalytic cracking, methanol-to-olefins, gas-to-liquids, biomass and recycle plastic pyrolysis, battery materials, poly silicons, dehydrogenation, methane pyrolysis and others. He also developed several engineering tools to design several aspects of fluidized beds, cyclones, diplegs, standpipes and risers. He has written either internally or externally over 150 papers in the area of fluid-particle systems. He has been teaching PSRI technical seminar to the industrial engineers from all over the world for the last 31 years. He has chaired several sessions at AIChE. He was chair of Group 3b and currently Chair of Particle Technology Division of AIChE. He received 2011 AIChE's Fluidized Processing Award sponsored by Dow Chemical Company

Current Membership List (36)

PROCESSING COMPANIES (20)

Albemarle U.S., Inc.
BASF Corporation
Bangchak Public Corporation Ltd.
BP Products North America
Chevron U.S.A., Inc.
Dow Chemical Company
Eneos (JXTG NIPPON OIL&ENERGY)
ExxonMobil Res. & Engineering
GTI Energy
Haldor Topsoe
HPCL
Indian Oil Corporation Ltd.
Marathon Petroleum Co.
Niron Magnetics
Owens Corning
Par Pacific Holdings Inc.
~~Phillips 66 Co.~~
SABIC
Sarpom SRL
Shell Global Solutions
Suncor / Syncrude Canada Ltd

NON-PROCESSING COMPANIES (16)

Aurora Hydrogen
Oxy/Carbon Engineering
CPFD Software, LLC
CZero Energy, Inc
Encina
Honeywell UOP
Idaho Environmental Coalition LLC
IFP Energies Nouvelles
KBR
Lmmus Technology
OMC Thermochemistry
~~Lyten~~
Siemens (CD-Adapco)
Technip Energies
Valmet Technologies
ZEG Power AS

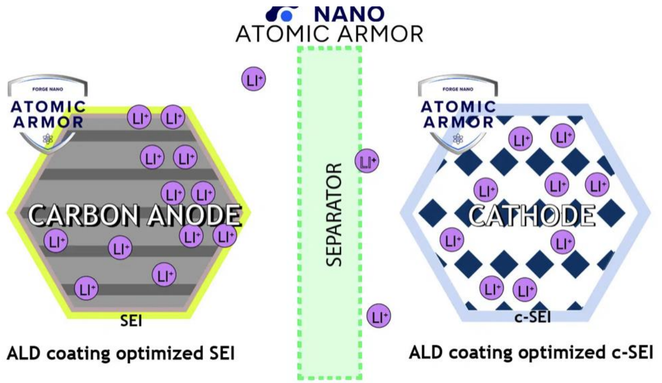
Emerging Technologies

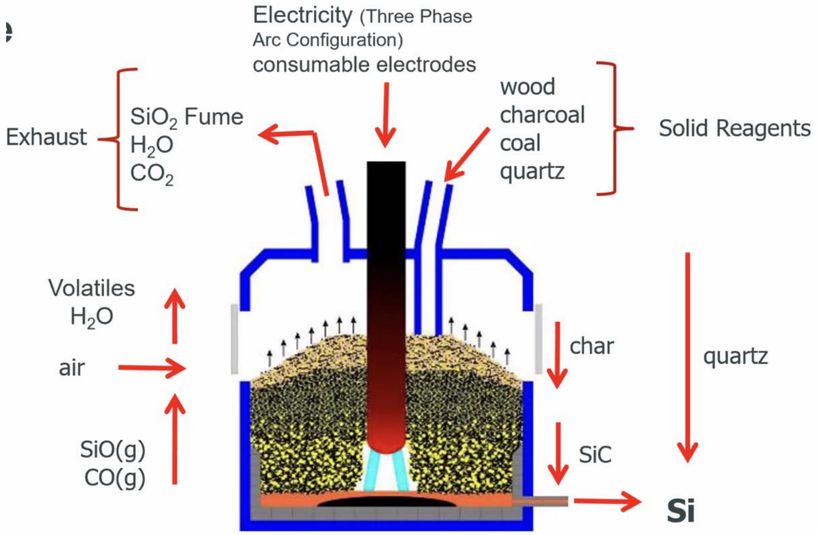
PSRI is the leading global expert in industrially relevant granular and granular-fluid unit operations

- Unit Operatons
  - Fluidized beds
  - Circulating fluidized beds
  - Cyclones
  - Standpipes
  - Packed beds
  - Slurries
  - Ebullated beds
  - Injectors
  - Feeders
  - Hoppers
  - Pneumatic conveying
    - Dilute and dense phase
- Capabilities
  - Unit design concepts
  - Hydrodynamic mapping
  - Reliability analysis
  - Risk analysis
  - Process Conceptualization
  - CFD, DEM, MP-PIC, ROM, PBM

Acrylonitrile,
- **Battery materials - Lithium, electrode materials, nickel**
- **Biomass gasification,**
- **Biomass (catalytic) pyrolysis,**
- Catalytic oxidation,
- Coal combustion, Coal gasification,
- **Chemical looping,**
- **Dehydrogenation,**
- Fluid coking,
- Fluidized catalytic cracking (FCC),
- Hydrogenation,
- Iron ore reduction
- **Low carbon and Direct/Indirect CO_2 capture,**
- Maleic anhydride,

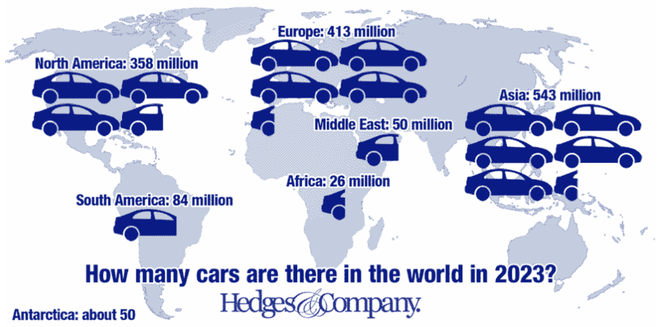
Oxychlorination,
- Methanol to Olefins (MTO),
- **Polycrystalline silicon,**
- Polyolefin reactors (PE and PP),
- **Pyrolysis of natural gas**
  - **Hydrogen production**
  - **Graphene**
  - **Carbon Nanotubes**
- **Recycle Plastic Pyrolysis,**
- Reforming,
- Sulfur capture operations,
- TiO_2 roasting via $TiCl_4$, and
- Waste remediation (MSW)

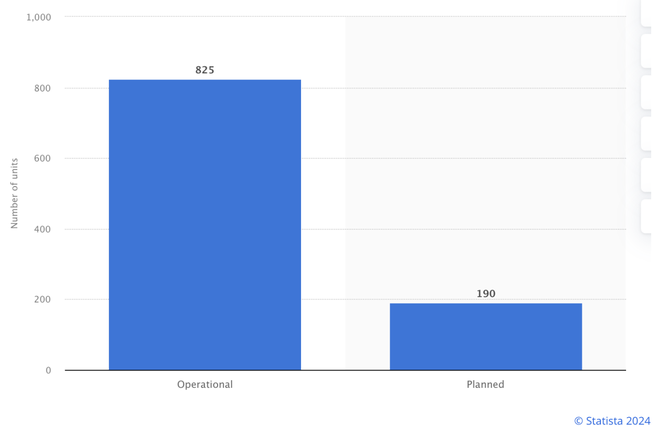


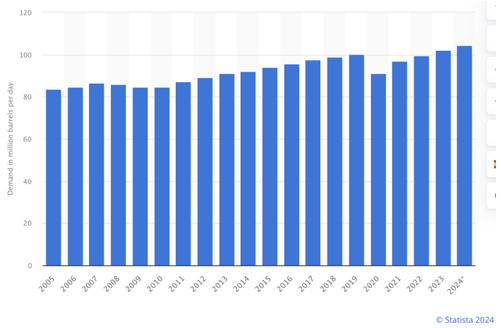


Current Fueling of Transportation

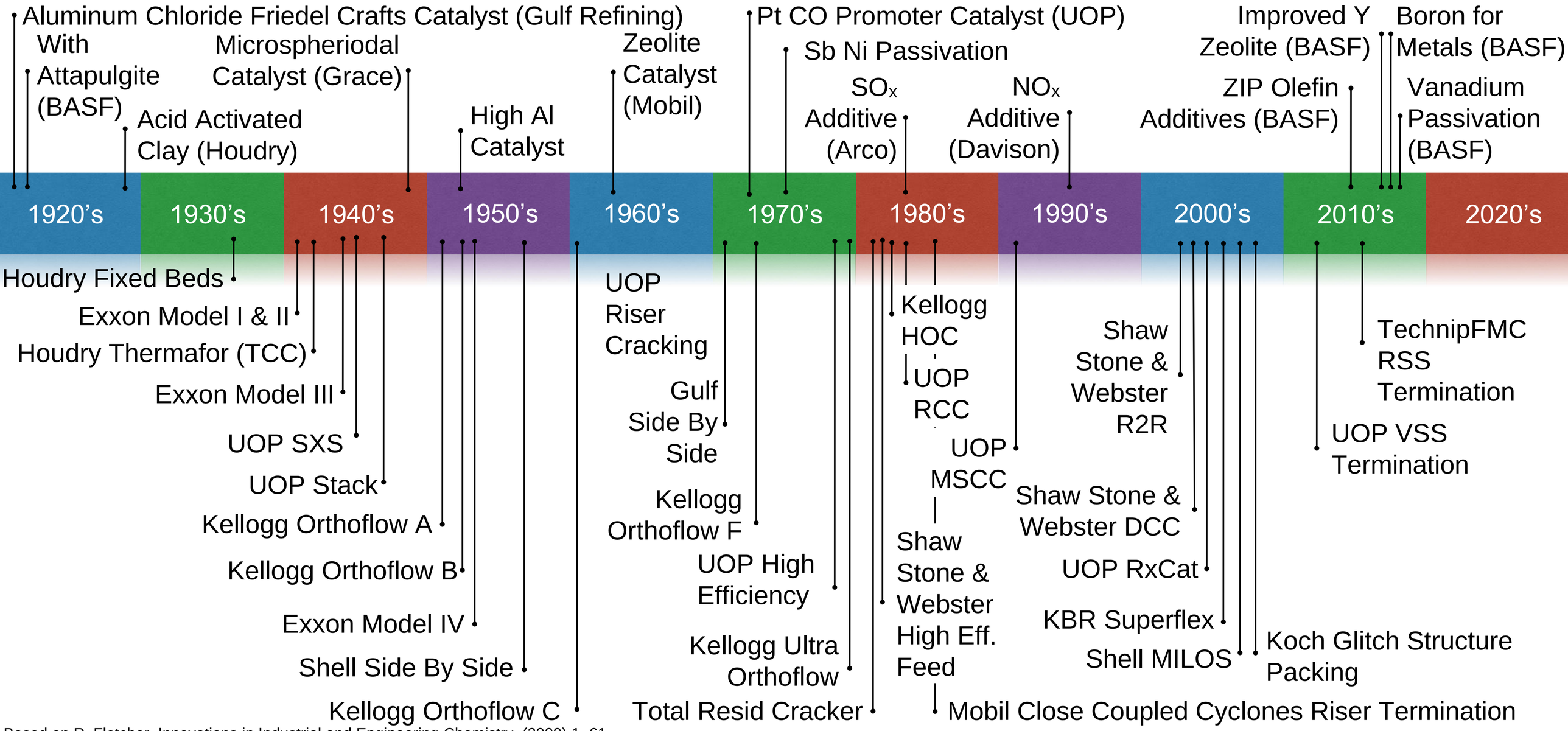
- There are over **1.5** billion passenger cars in the world
- Today **825** active refineries in the world fueling the cars, heavy trucks, and planes consuming **100 million barrels** of crude oil per day
- In 2023, the auto industry in the United States sold approximately **15.5 million** light vehicle units
- In the United States, new electric car registrations totaled **1.4 million** in 2023, i.e., 9.6% of total sales





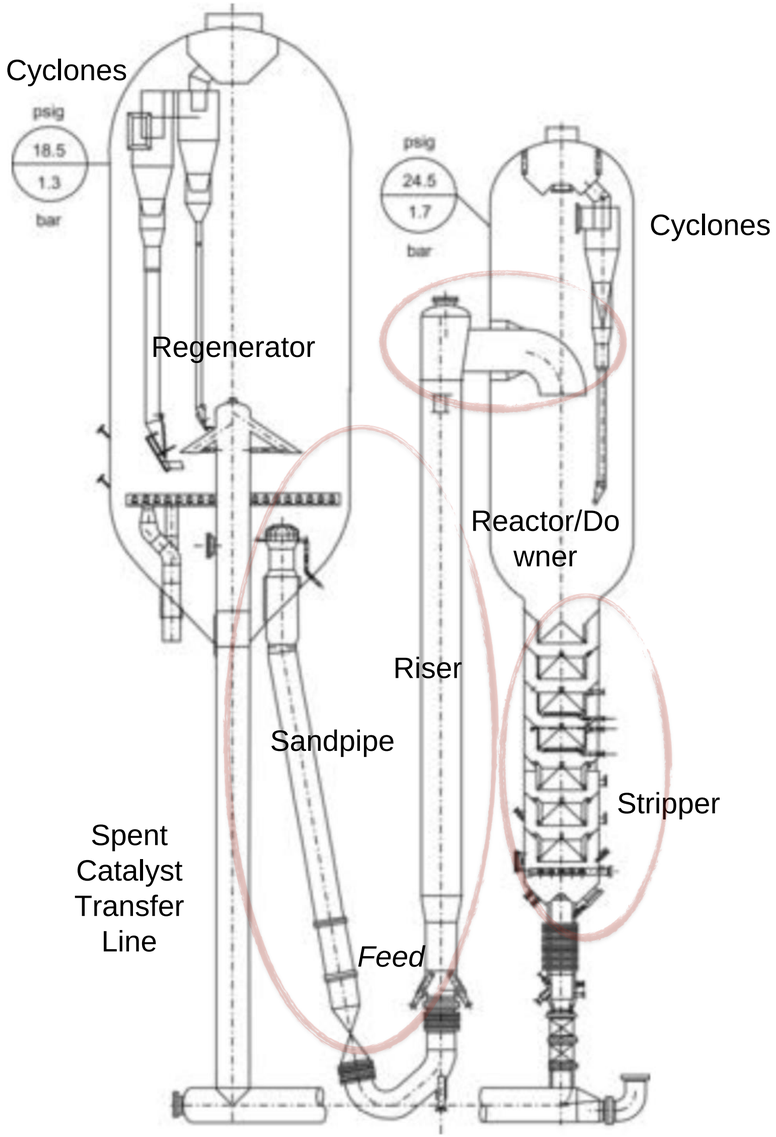


History of Hydrocarbon Cracking

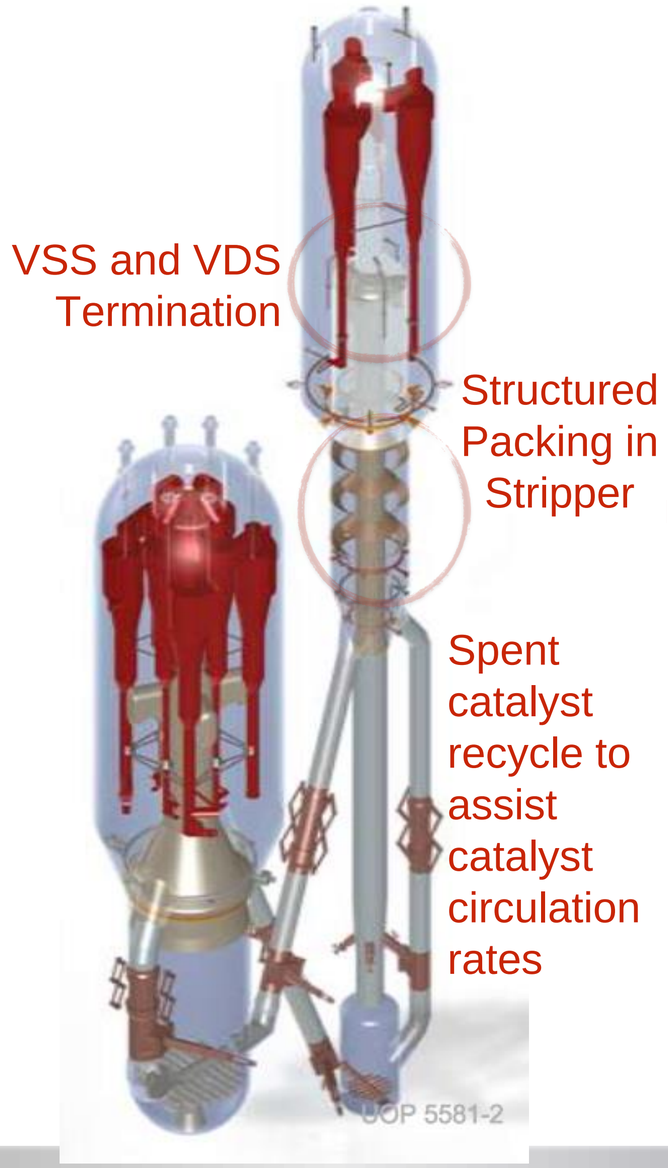


Based on R. Fletcher, Innovations in Industrial and Engineering Chemistry, (2009) 1–61.

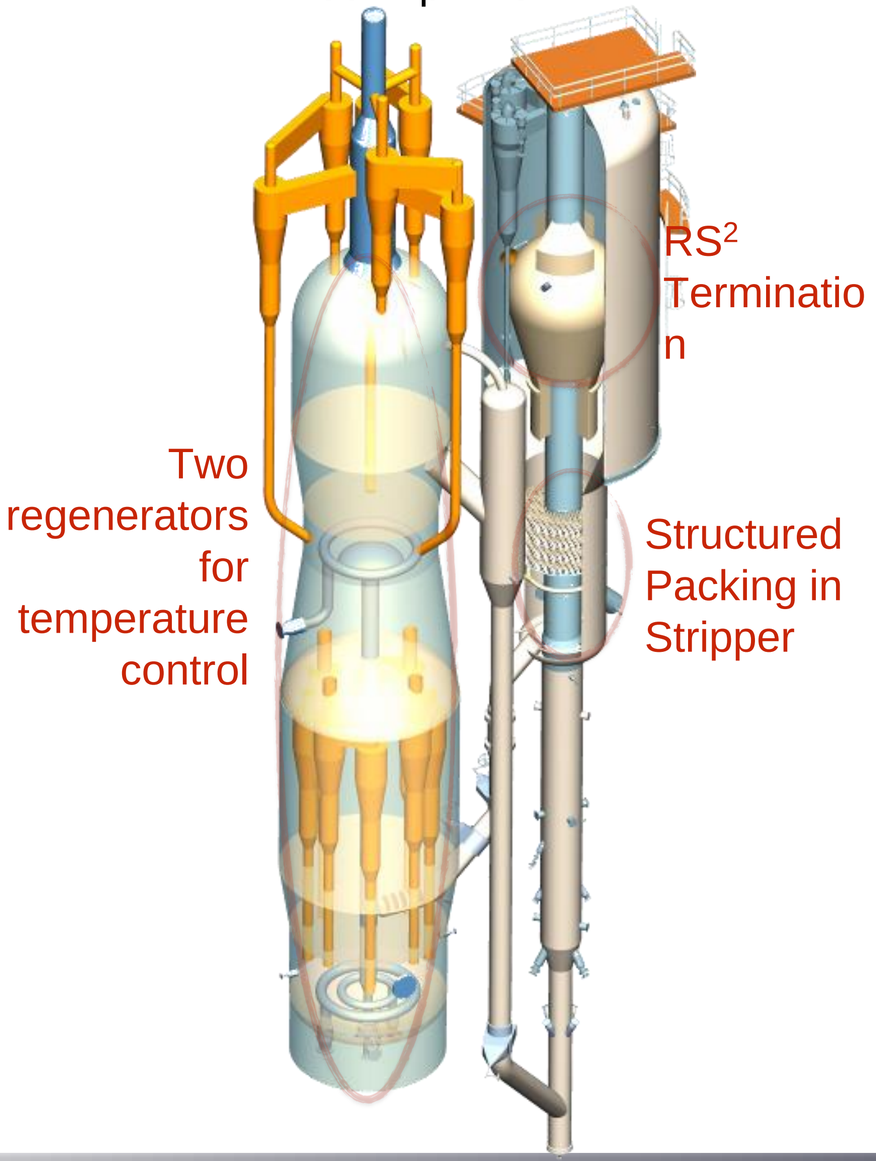
Todays FCC Technology



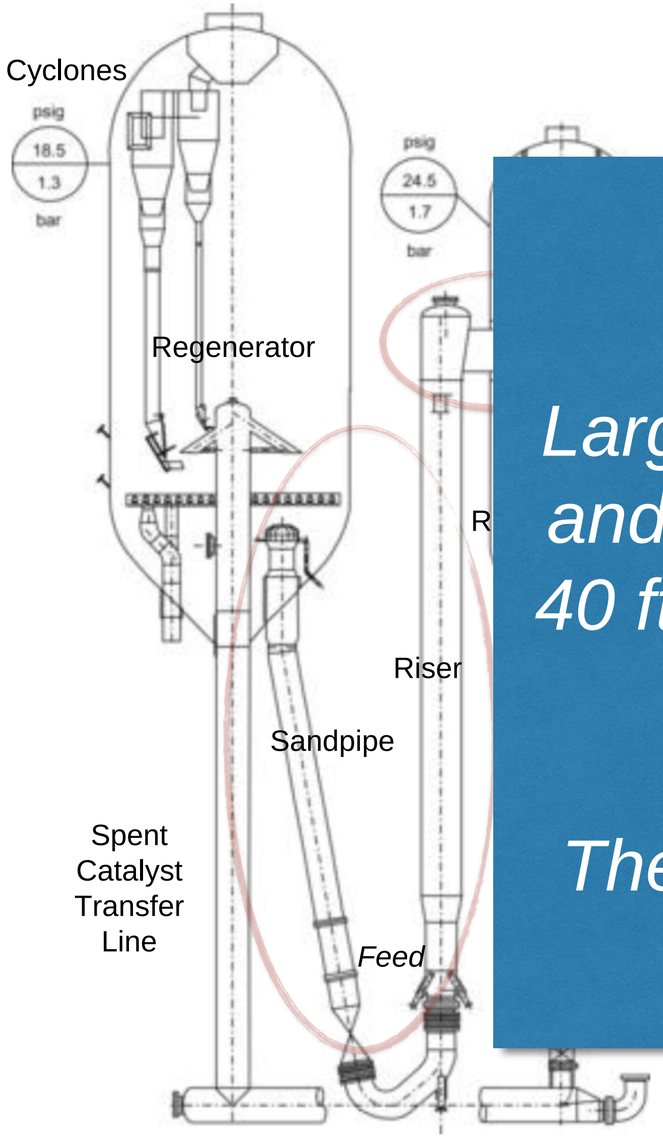
UOP RxCat



TechnipFMC R2R



Todays FCC Technology



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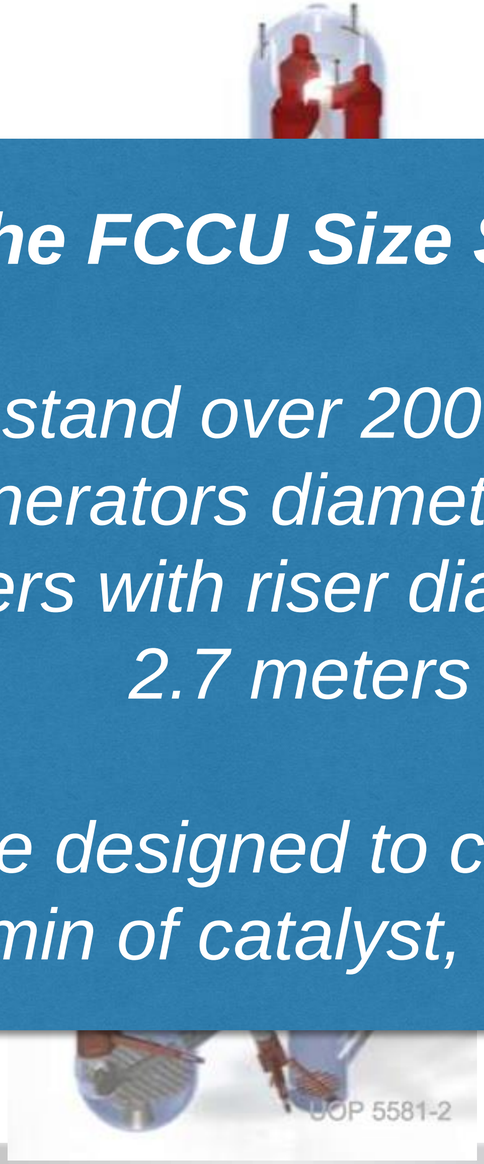
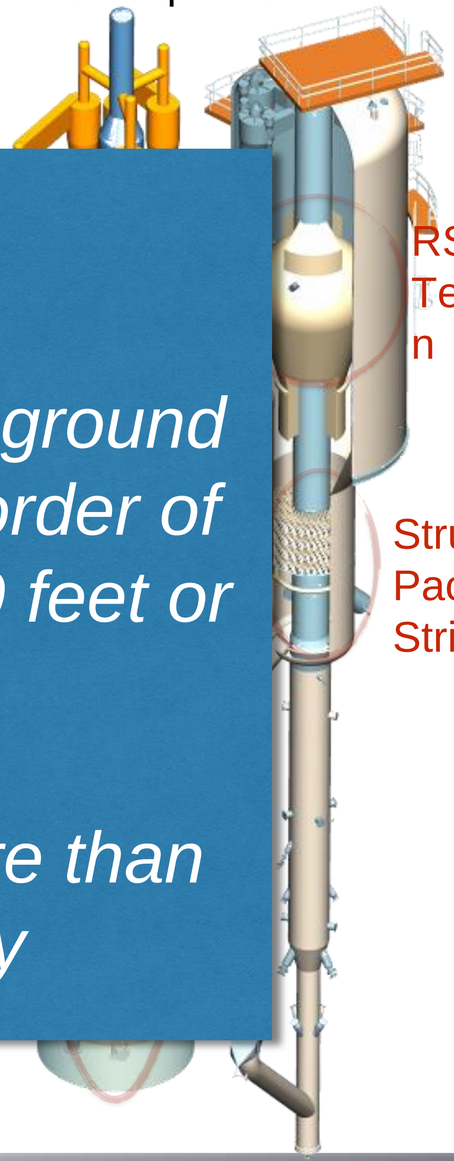


TechnipFMC R2R



RS^2 Termination

Structured Packing in Stripper

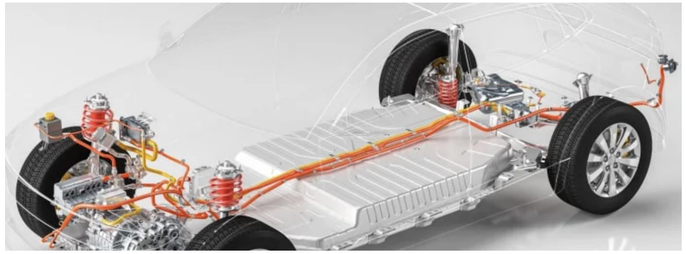
The FCCU Size Scale

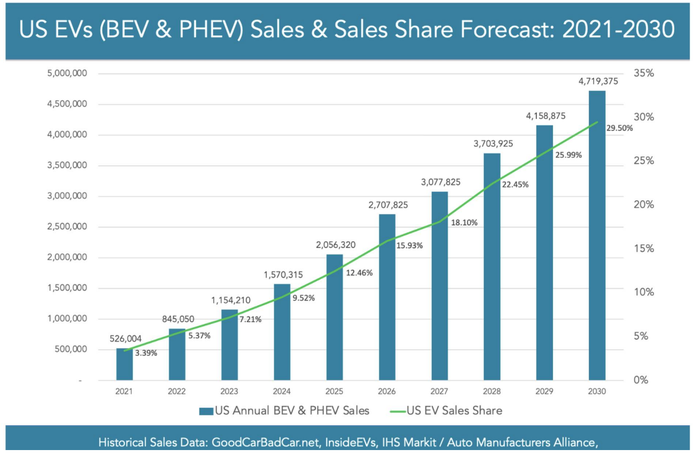
Larger FCCUs stand over 200 feet above ground and have regenerators diameters on the order of 40 ft or 12 meters with riser diameters of 9 feet or 2.7 meters

These units are designed to circulate more than 140 MT/min of catalyst, continuously

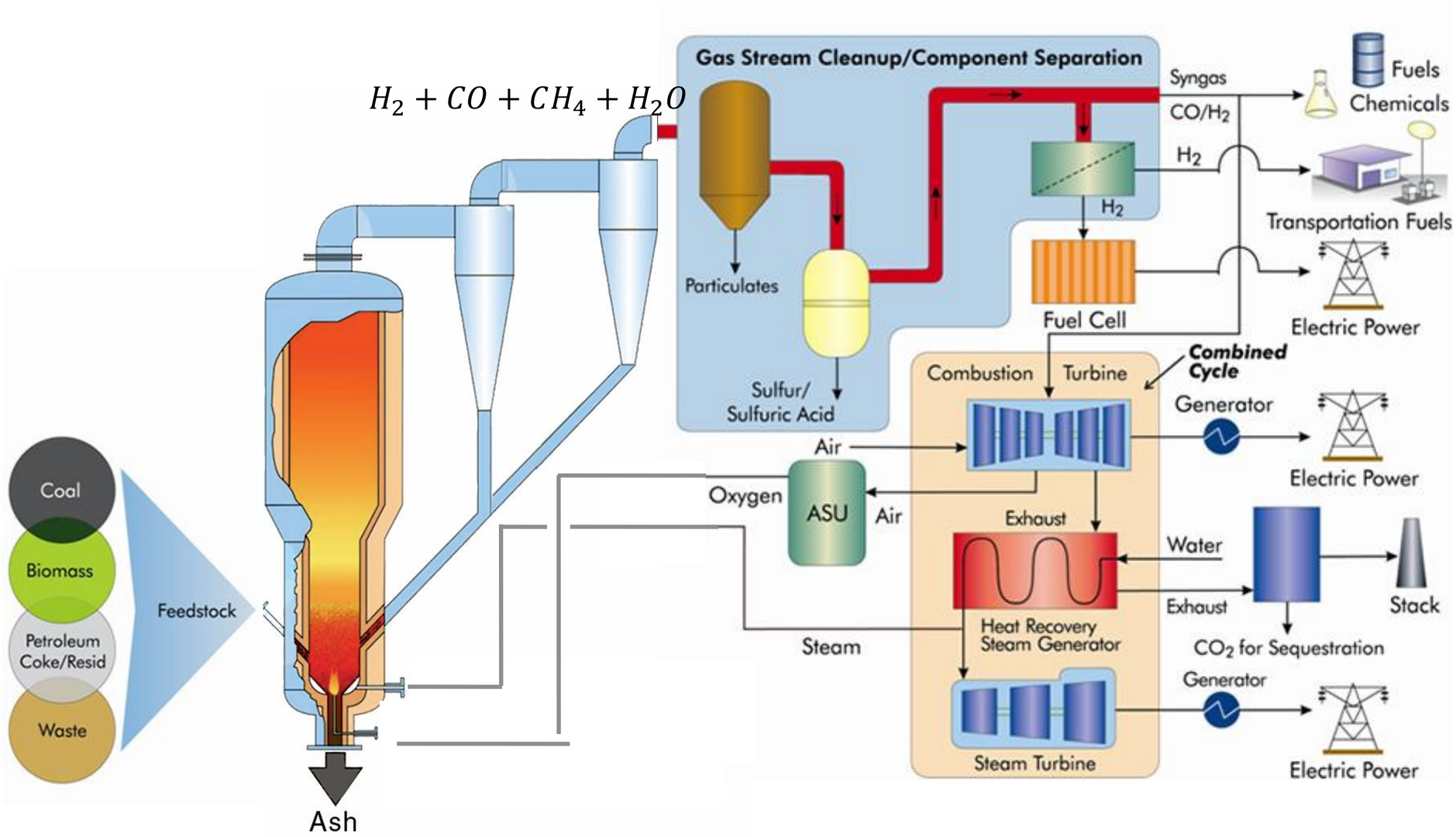
Electrification of Transportation in the US

- In the **United States**, new electric car registrations totaled **1.4 million** in 2023, i.e., 9.6% of total sales
- A typical EV battery, weights about 480 kg, has about 8 kilograms of lithium, 14 kilograms of cobalt, and 20 kilograms of manganese
- Today, US is using 8 kg * 1,400,000 vehicles/year 2023 = **11,200 MT/year** of lithium
- Projected electric car sales by 2030 are **4.2 million** vehicles, i.e., amount of lithium needed = **33,600 MT/year**, which is three fold increase in 7 years
- What's the the exact role of the fluidized beds? Proprietary & Confidential
- What does the history teach us? Fluidized beds will play a major role in scaling -up the lithium processes



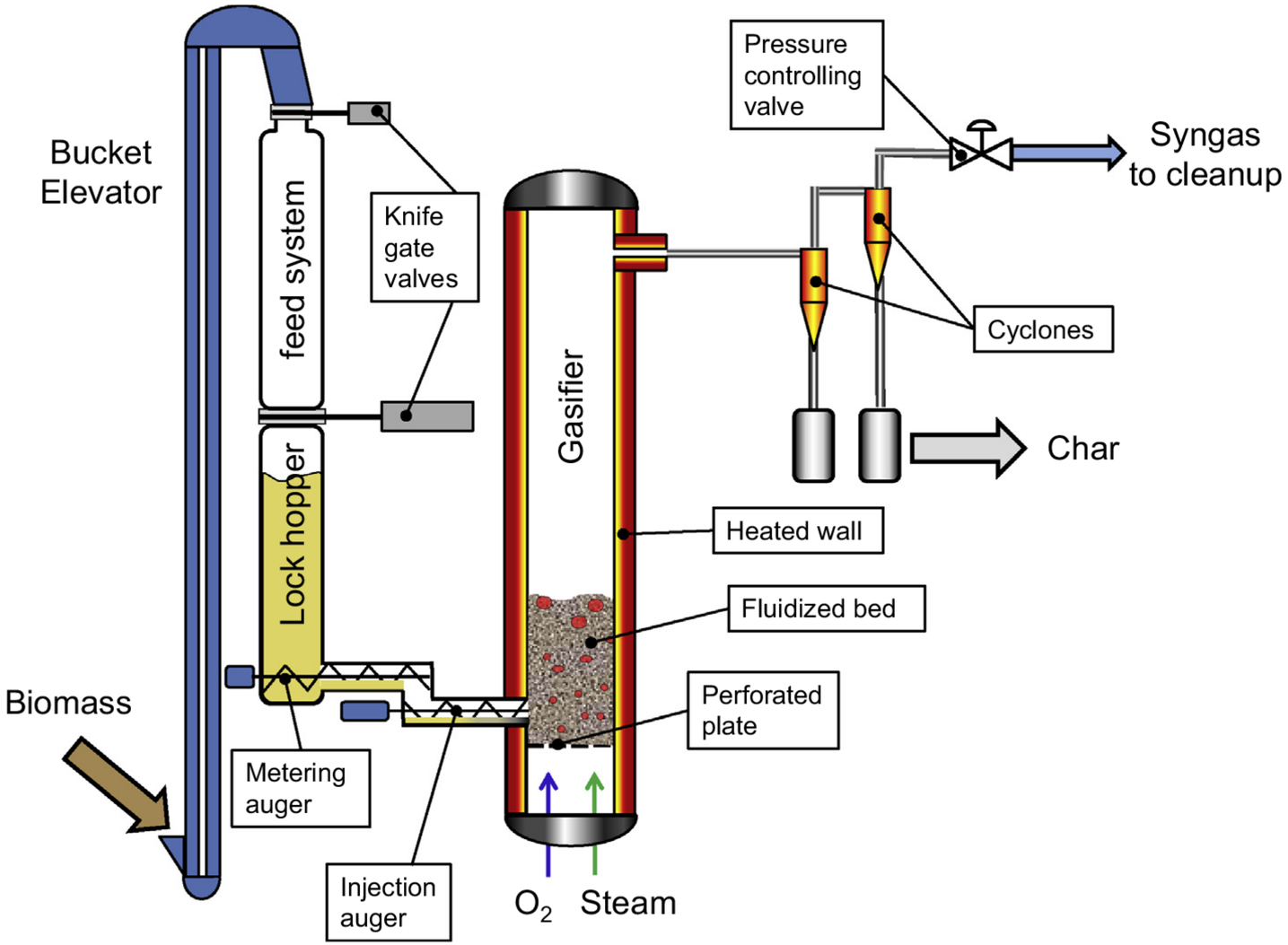


Gasification



- Gasification involves
  - Dehydration
  - Pyrolysis
  - Combustion
  - Water-gas shift
- Can be air or oxyblown
- Operates at
  - 800 to 1050°C
  - Up to 10 bar

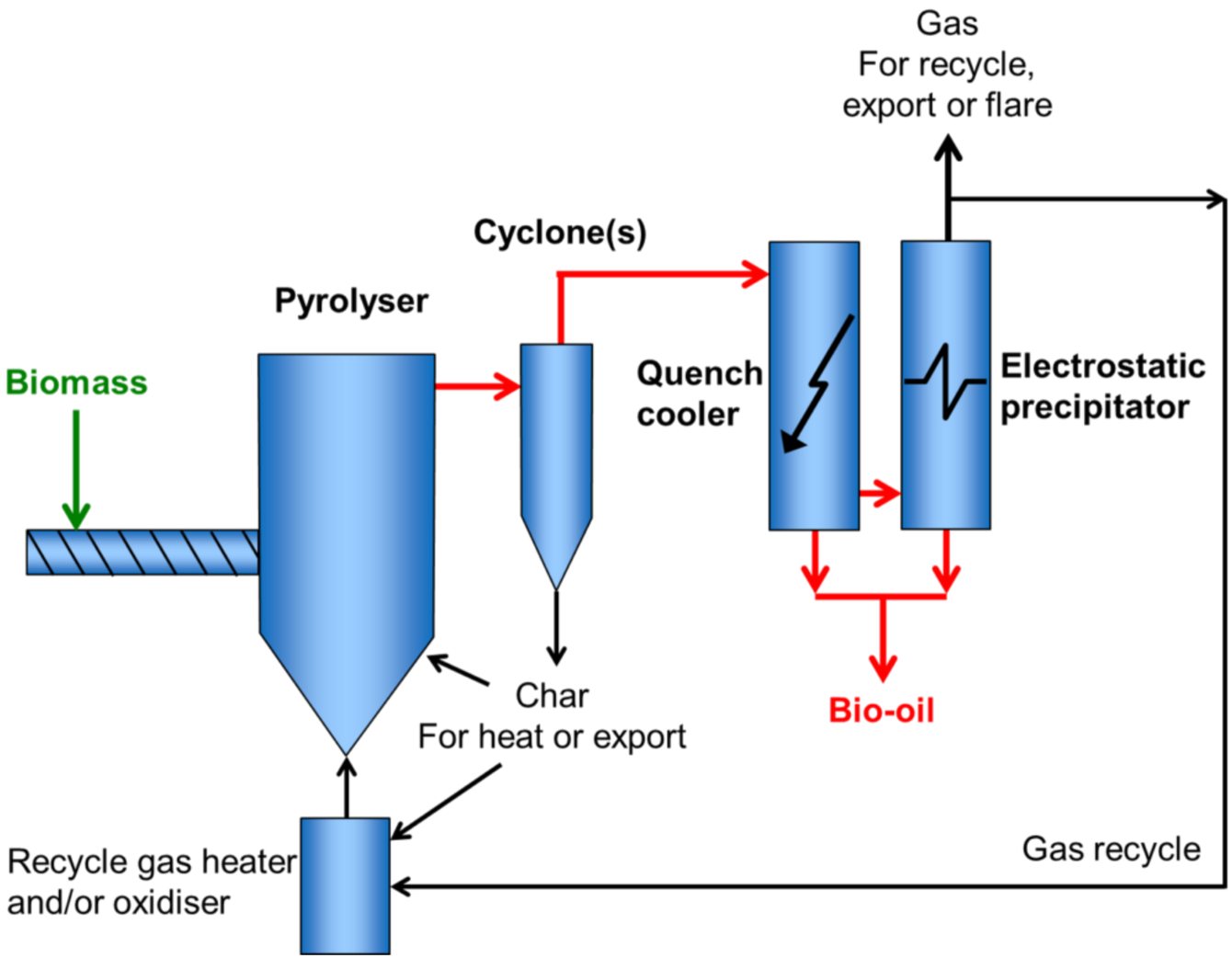
Biomass Gasification



Iowa State University

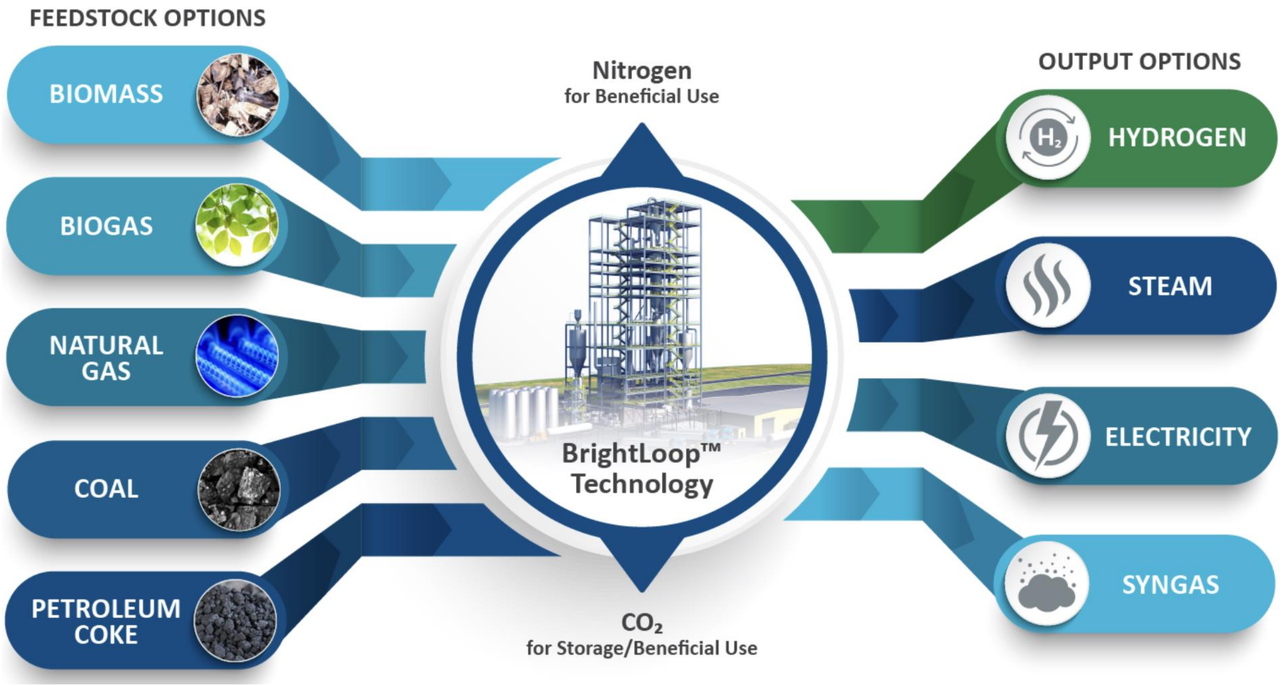
- Array of lock hoppers are needed for high pressure feeding of solids
- For biomass, the moisture content is problematic
  - High moisture contents shifts the H_2/CO ratio unfavorably
- Feedstocks include
  - Wood
  - Switch grass
  - Corn stover
  - Municipal solid waste
  - Manure
  - Sludge

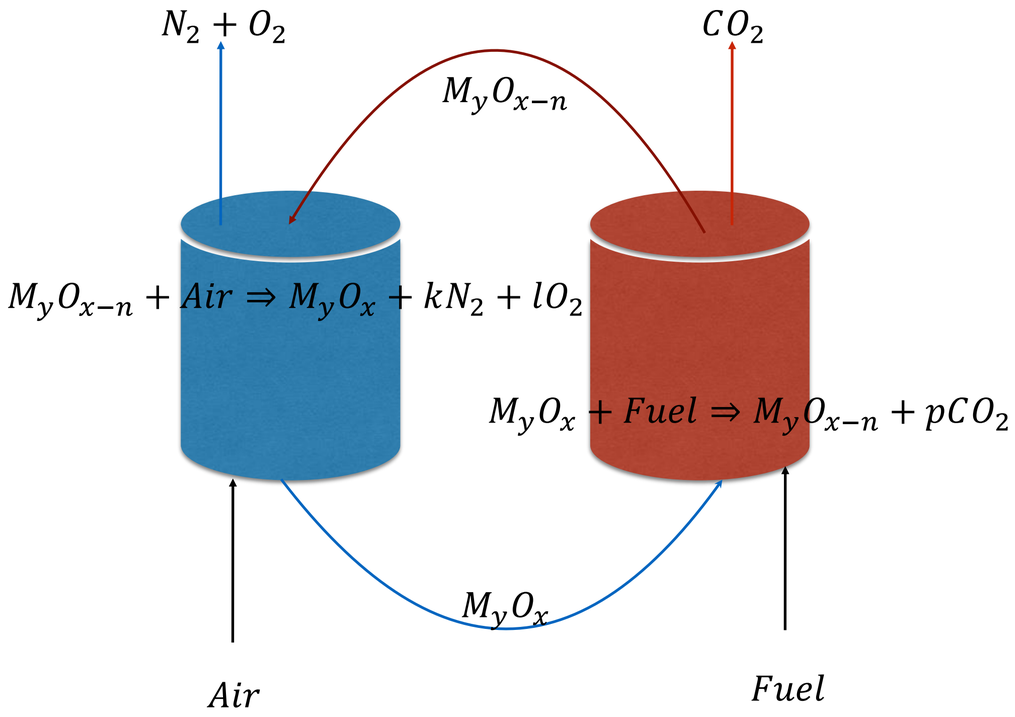
Biomass/Plastic Pyrolysis



- Commercial applications include fluidized bed and circulating fluidized bed designs
- Pyrolysis reactors operate at 400 to 500°C at near atmospheric pressures
  - Reactors are less expensive than the higher pressure gasifiers
  - Feed the reactors is less complicated as well
- However, pyrolysis reactions produce oxygenates and tars which needs to be managed in order to meet bio-oil specifications

BrightLoop™ Low-Carbon Hydrogen Technology





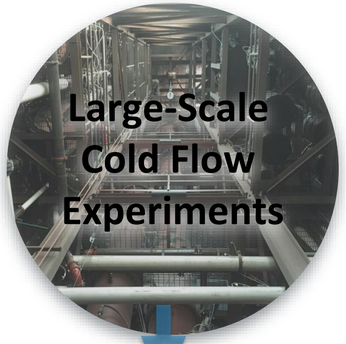
- Reduced metal carriers are used to extract oxygen from the atmosphere
  - Metal oxides are used as the oxygenates
- The unit is a circulating redox loop for the carriers

https://www.babcock.com/home/environmental/decarbonization/low-carbon-hydrogen/

Direct CO_2 Capture from Air

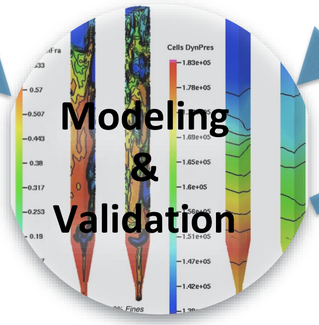
Stratos Occidental Petroleum Carbon-Capturing Plant Under Construction Near Odessa, Texas, NY Times

The PSRI Strategy for Scaling-Up a New Process



Chemistry is Proven in Lab-Scale Fixed Bed and/or Fluidized Bed → *Design and Operate Pilot-Scale Hot Fluidized Bed* → *Design and Operate Hot PDU Unit for Long Periods of Time* → *Obtain Large-Scale Cold Flow Hydrodynamic Data* → *Design and Construct the Commercial Unit*

CPFD Software, our Strategic Partner, can Help Here



PSRI Engineers (11)

Mr. Mke Arrington

Dr. Yeook Arrington

Mr. Bhaumik Bheda
(Start date: August, 2024)

Ms. Lauren Endress

Mr. Matt Hankosky

Dr.. Allan Issangya

Dr. S.B. Reddy Karri

Dr. Ted Knowlton

Ms. Kristin Lai

Dr. Franciso Sanchez

Ms. Eleanor Wong

- Actively looking to add potential Technical Director

Caption