Business

- Reminder – Student Ratings for this class
- Schedule
  - Friday – student presentations (10 min)
  - Monday – final exam review (Andrew)
  - Wednesday – final exam (30 min oral)

Practical Combustion

Class 16

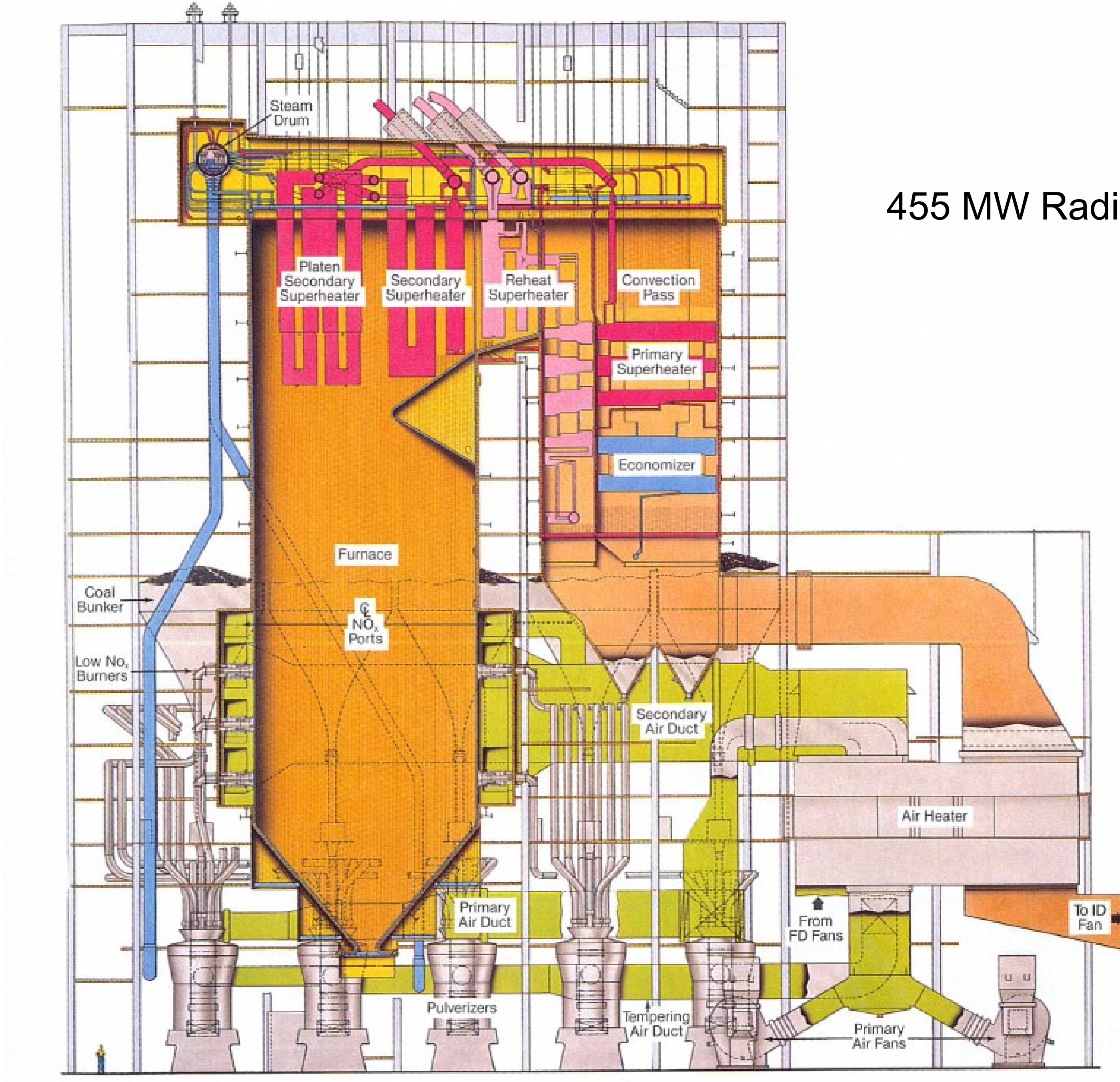
1a. Comparison of Combustors

	Fixed Bed	Fluidized Bed	Entrained Flow
Particle Size	10-50 mm	1.5-6 mm	1-100 μm
Operating T (K)	< 2000	1000-1400	1900-2000
Residence Time (s)	500-50,000	10-500	1-2
Coal Feed Rate (kg/hr)	< 40,000 (BYU heating plant was at 5000)	< 40,000	< 450,000
Advantages	Simple Low grinding costs	Low SO_x & NO_x Low slagging Multi-fuel Low corrosion	High efficiency High capacity
Disadvantages	Emissions, especially particulates Efficiency Low capacity	Feeding fuel Softening coal Low capacity Risk (not established)	High NO_x Fly ash capture Grinding costs

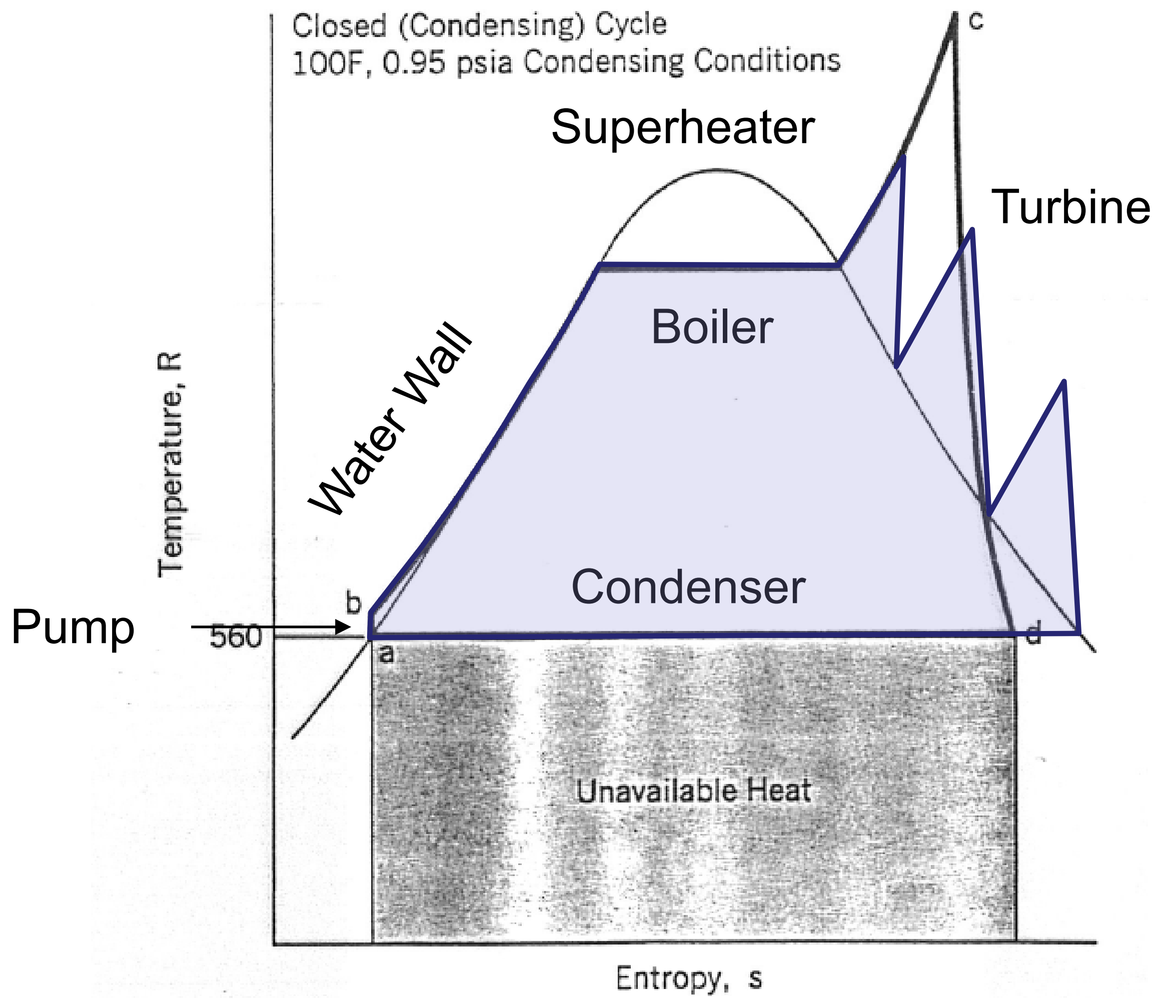
Modified from Table 5.2 in Smoot & Smith, 1985

From Steam, by Babcock & Wilcox

455 MW Radiant Boiler



Rankine Cycles



Types of Boilers

- Subcritical (38% efficiency, new)
  - 2400 psi (steam pressure)
  - T_{steam} = 1000°F
- Supercritical (42% efficiency, new)
  - 3500 psi
  - T_{steam} = 1000°F
- Ultrasupercritical (44% efficiency, new)
  - 4400 psi
  - 1150°F

Gasifiers

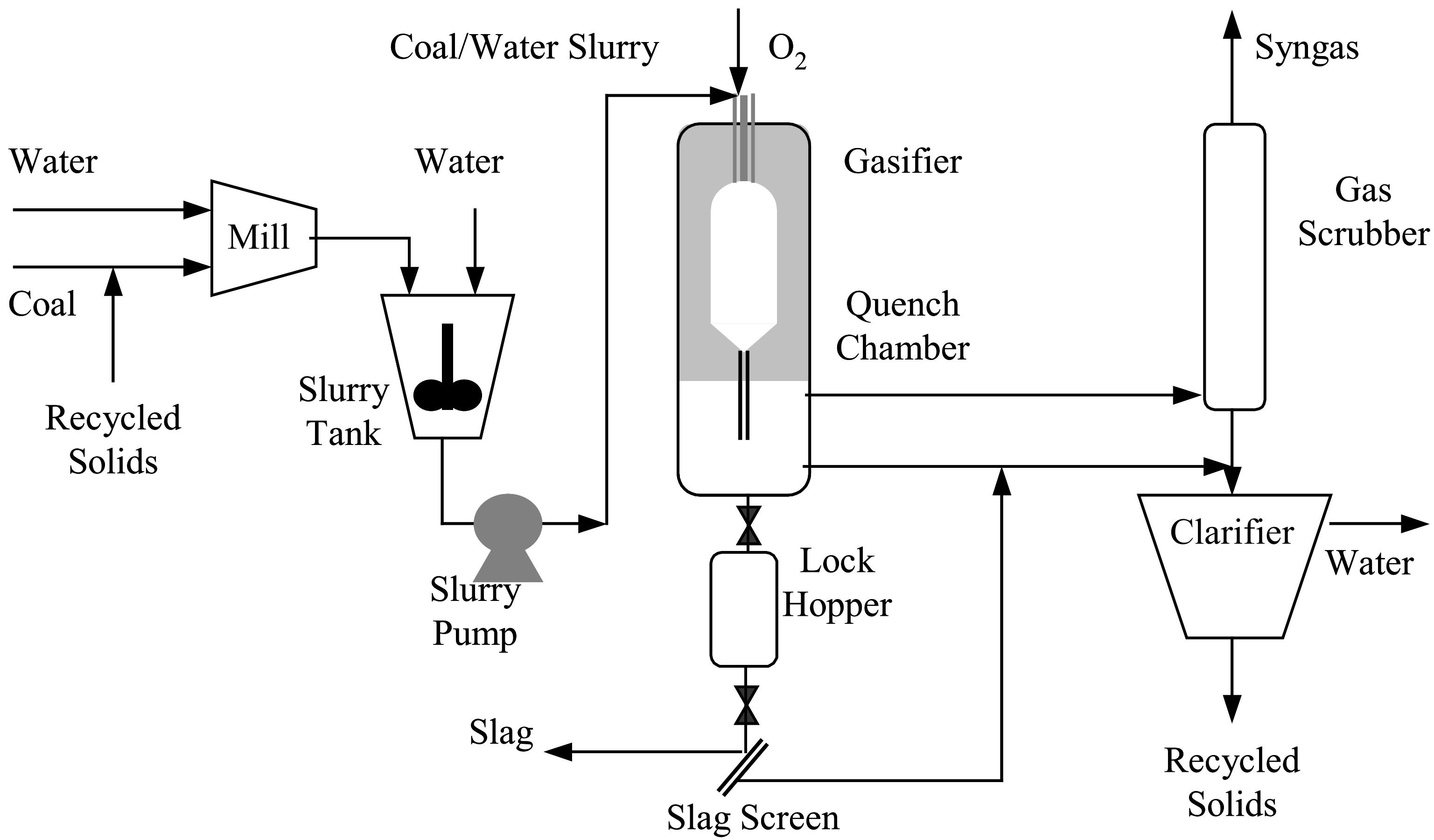
- Pretty much the same story as combustors
- Challenges:
  - Getting heat to where gasification happens
  - Slagging
  - Air separation unit required?
- Pressure?
  - Reduces size of gasifier
  - Adds complexity
    - Feeding
    - Disposing of ash
    - Lower volatiles

1b. Comparison of Gasifiers

Modified from Table 6.1 in Smoot & Smith, 1985

	Fixed Bed	Fluidized Bed	Entrained Flow
Particle Size	6-50 mm	0.5-2.5 mm	10-150 μm
Operating T (K)	1150-1300	600-1470	1150-2500
Residence Time (s)	1-3 hrs	20-150 min	0.4-12 s
Pressure (atm)	0.1-2	1-100	1-300
O_2/Coal ratio (mass)	0.14-0.81	0.25-0.97	0.28-1.17
$CO+H_2$ (mol%)	39-66	2-80	35-91
CH_4 (mol%)	2-15	3-68	0.1-17
High Heating Value (Btu/SCF)	250-320	300-800	115-550
Advantages	Established technology (Lurgi) Low thermal losses High turndown ratio	Multi-fuel, multi-size Moderate heat losses	Small, simple design High capacity per volume
Disadvantages	Low capacity	Softening coal Low capacity Risk (not established)	Down time due to wear of refractory and injectors

GE Gasifier System



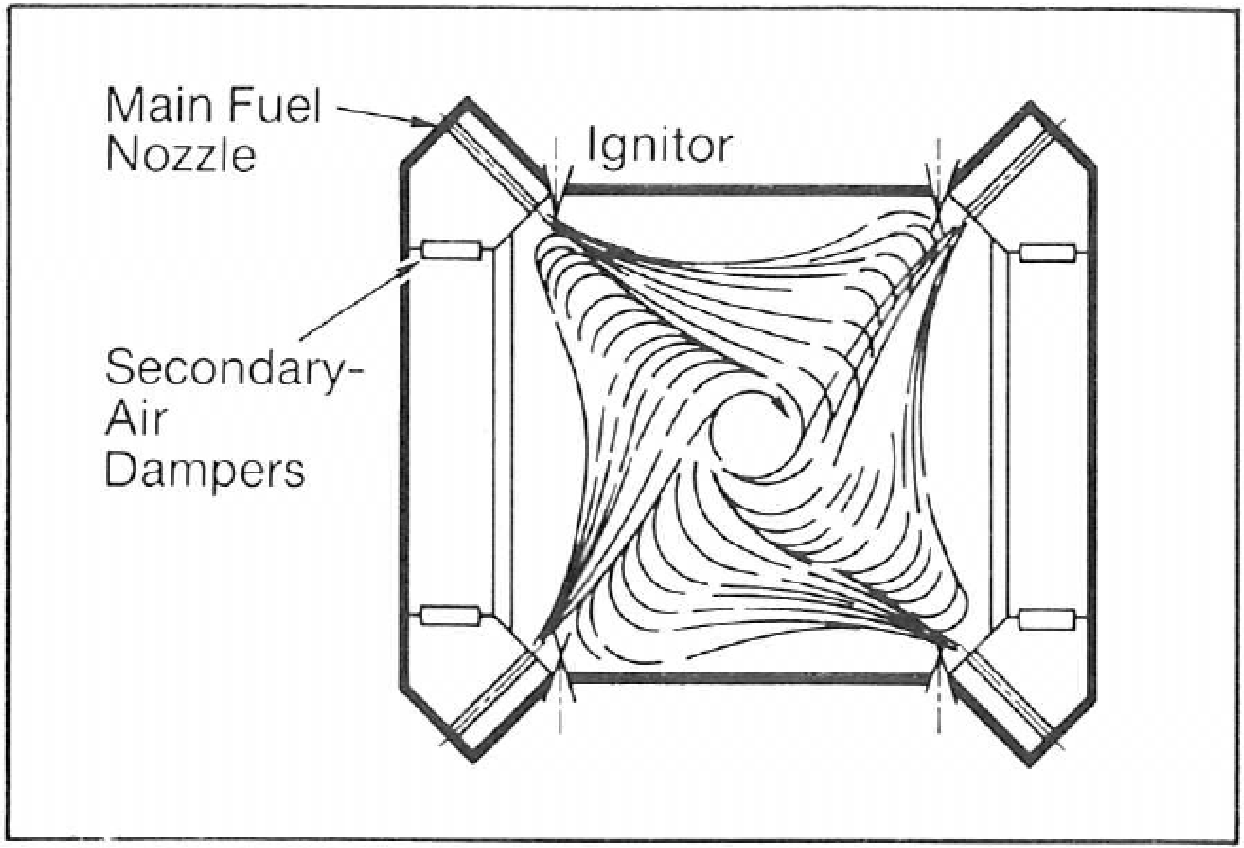


Fig. 3. **Tangential firing pattern**

From Combustion: Fossil Power Systems, by Combustion Engineering

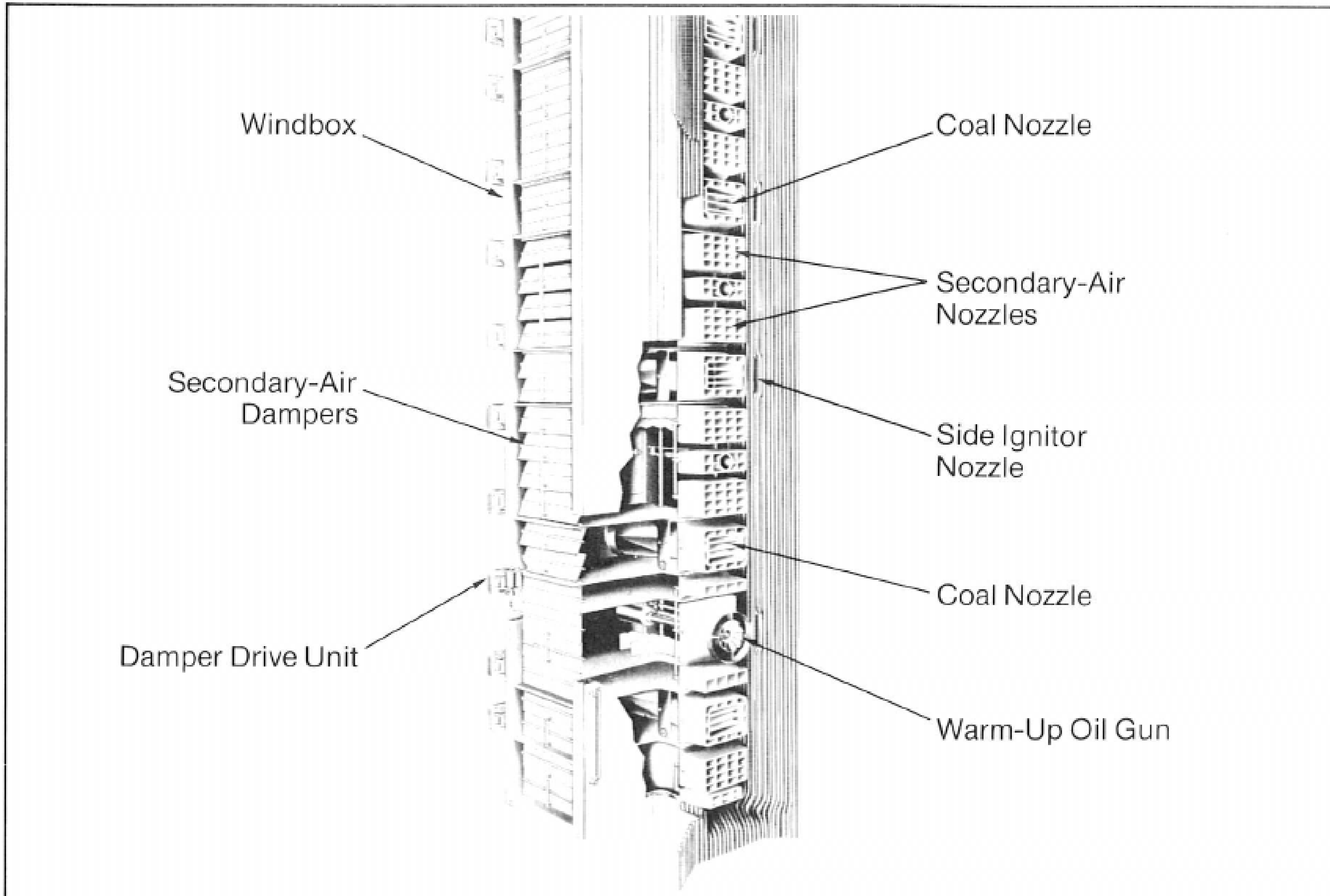


Fig. 4 **Arrangement of corner windbox for tangential firing of coal**

From Combustion: Fossil Power Systems, by Combustion Engineering

2. Wall-Fired vs. Tangential

Tangential

- Lower NO_x due to large swirl zone
- More difficult to tune

Wall-Fired

- Less complex
- Easier to tune individual burners

3. Figures of Equipment

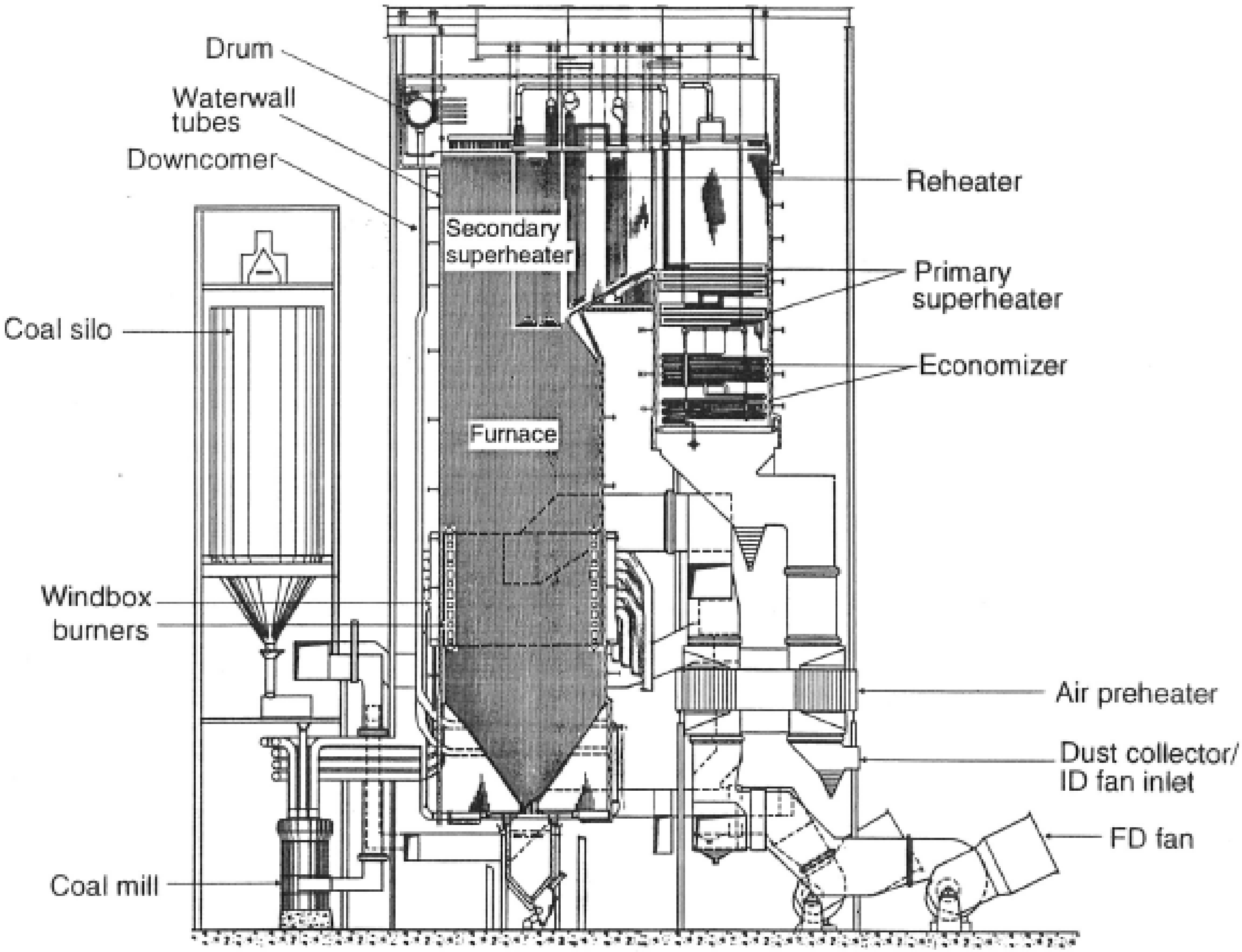
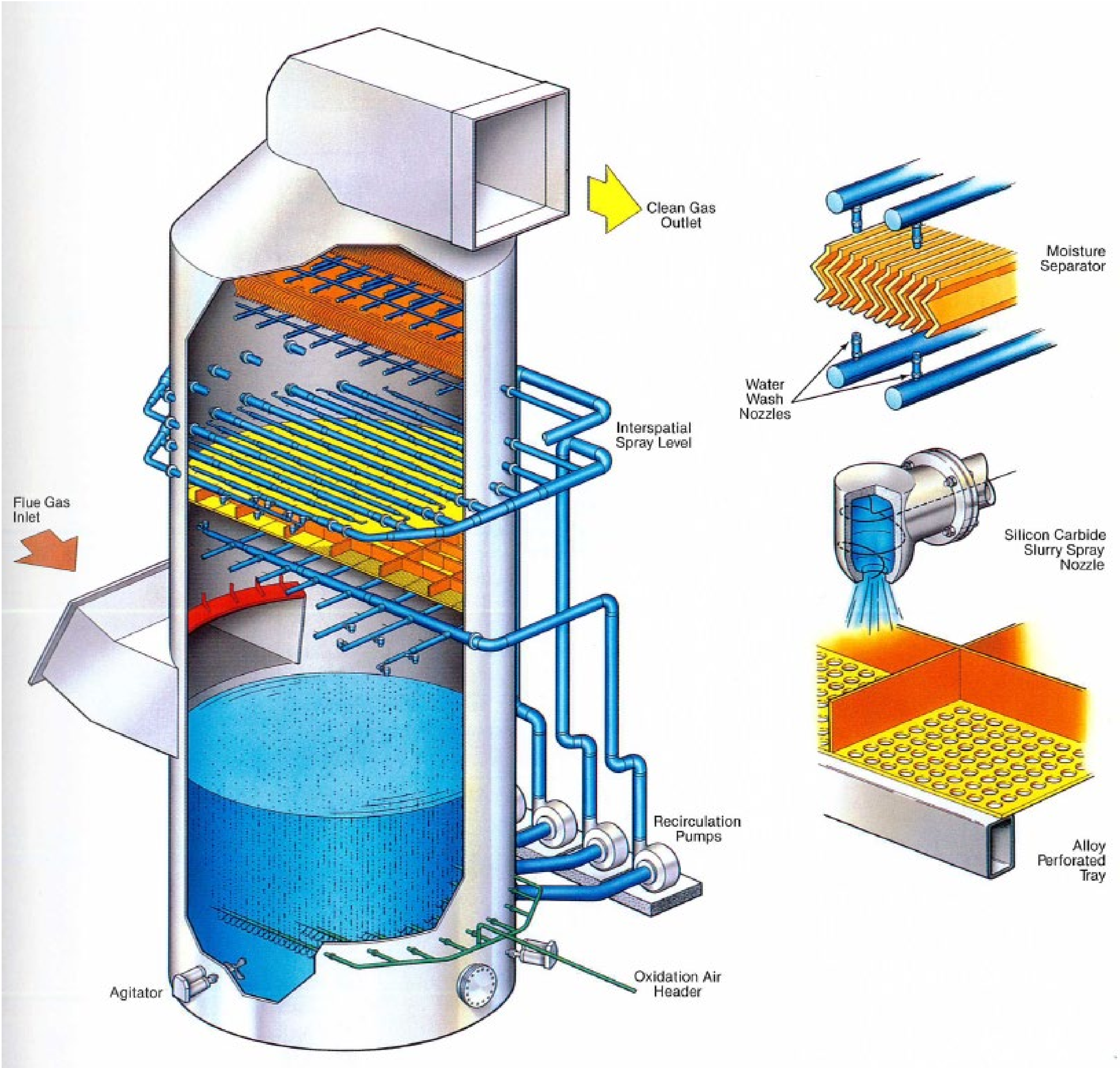


Fig. 1.10 Tangentially fired boiler (published with permission from ref. 36).

From Steam, by Babcock & Wilcox



Limestone Scrubber

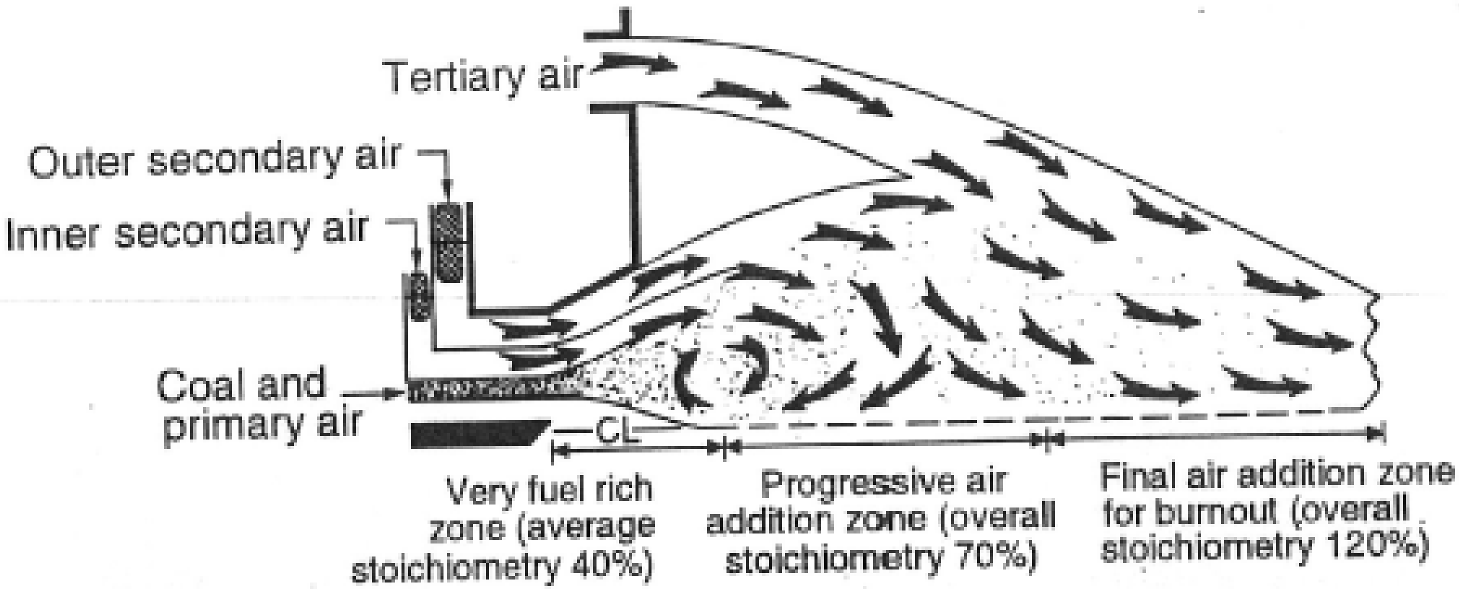


Fig. 1.12 Distributed mixing burner concept (published with permission from ref. 36).

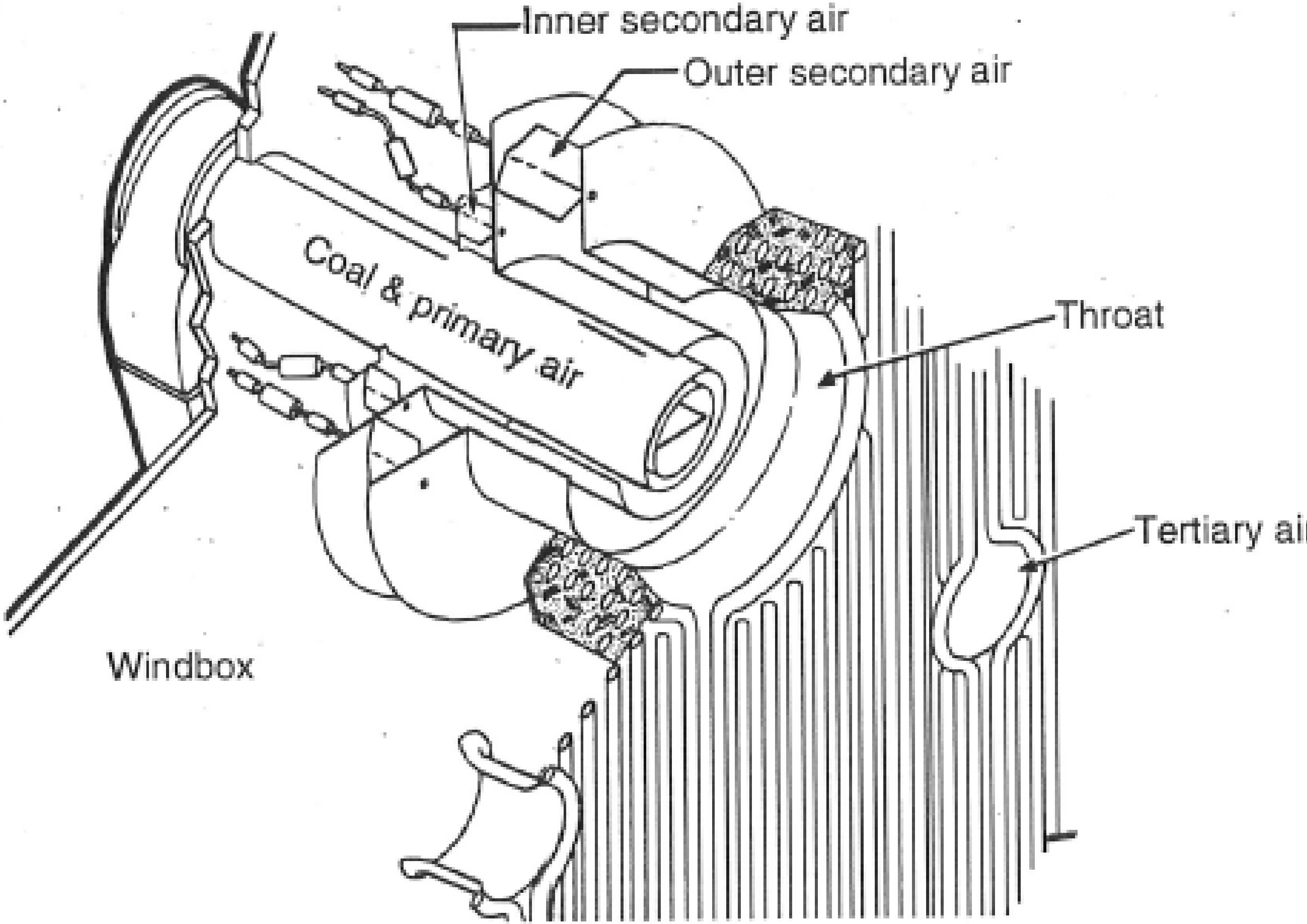


Fig. 1.13 Distributed mixing burner (published with permission from ref. 36).

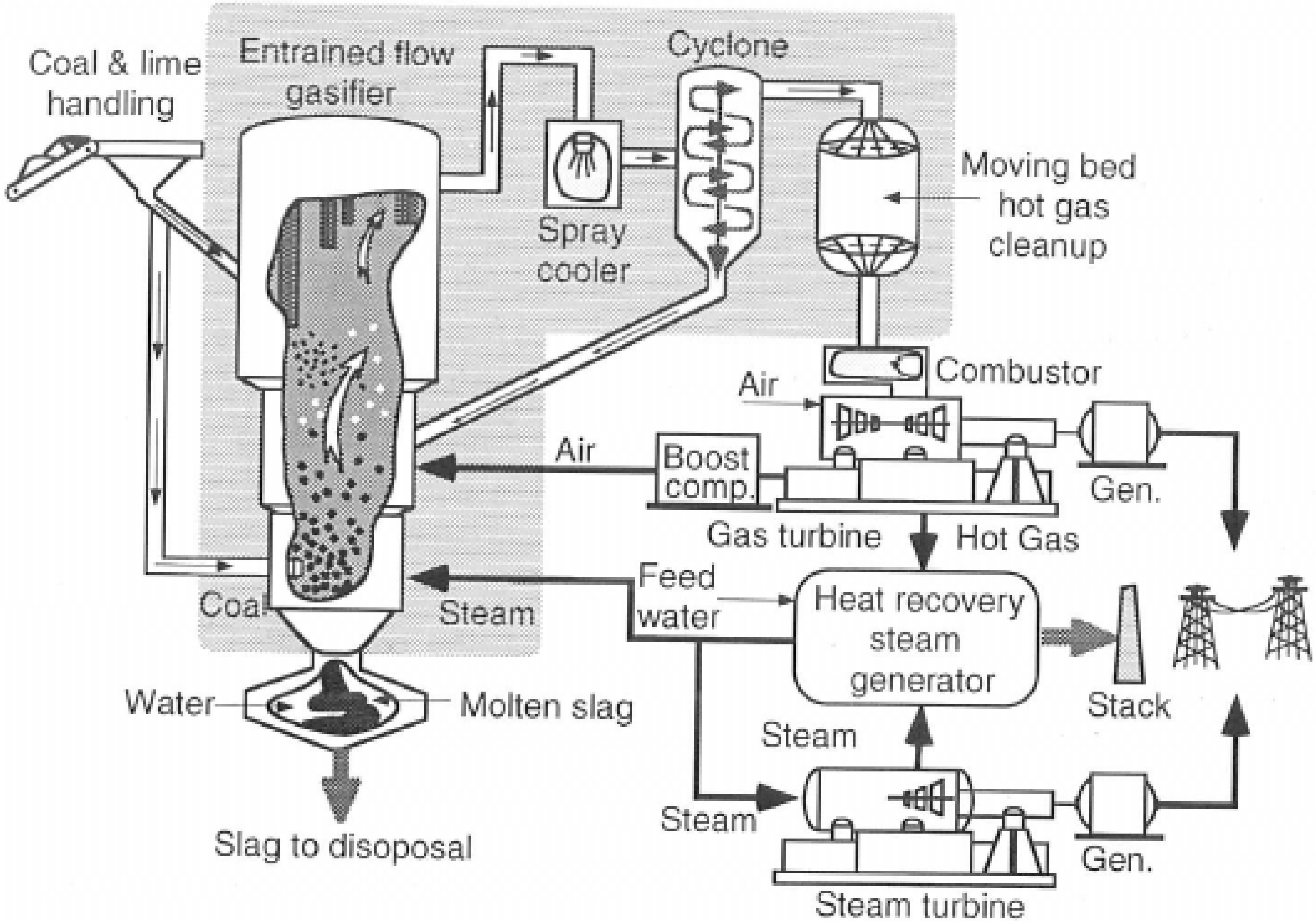
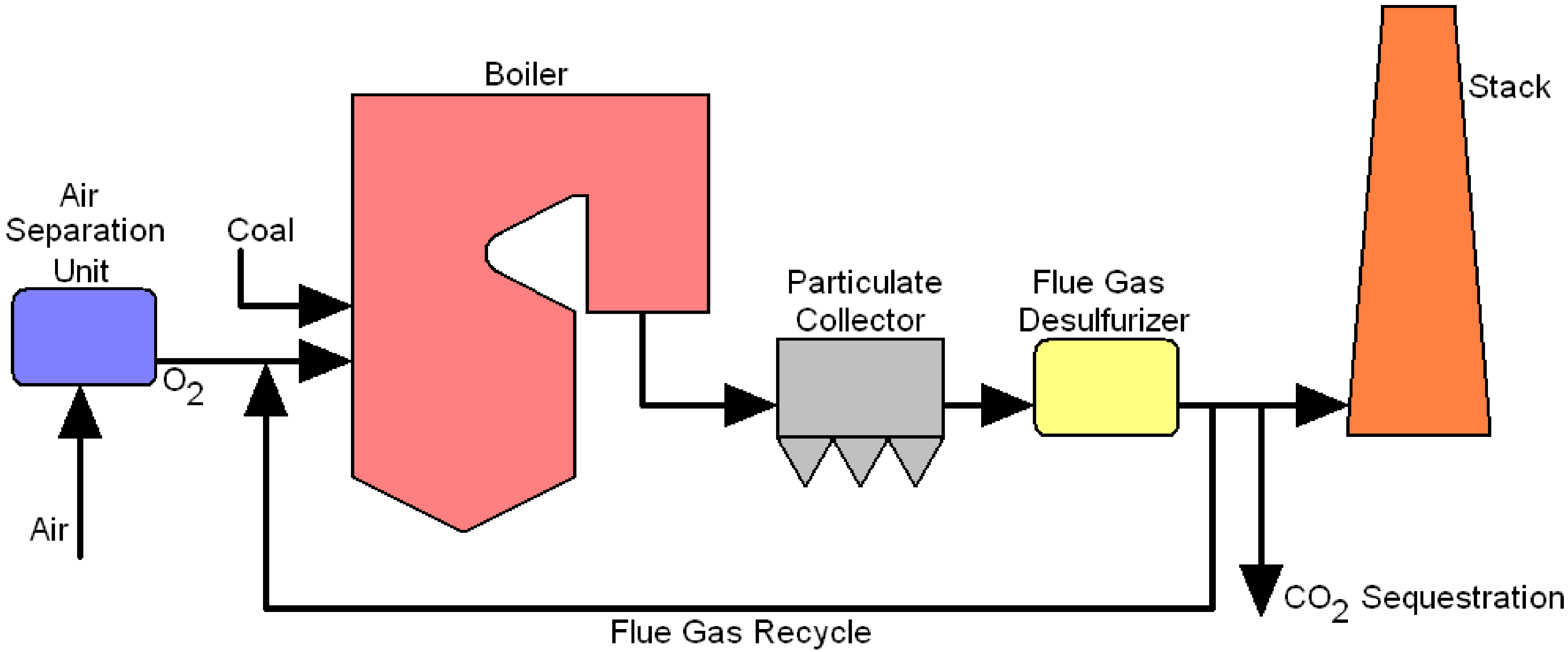
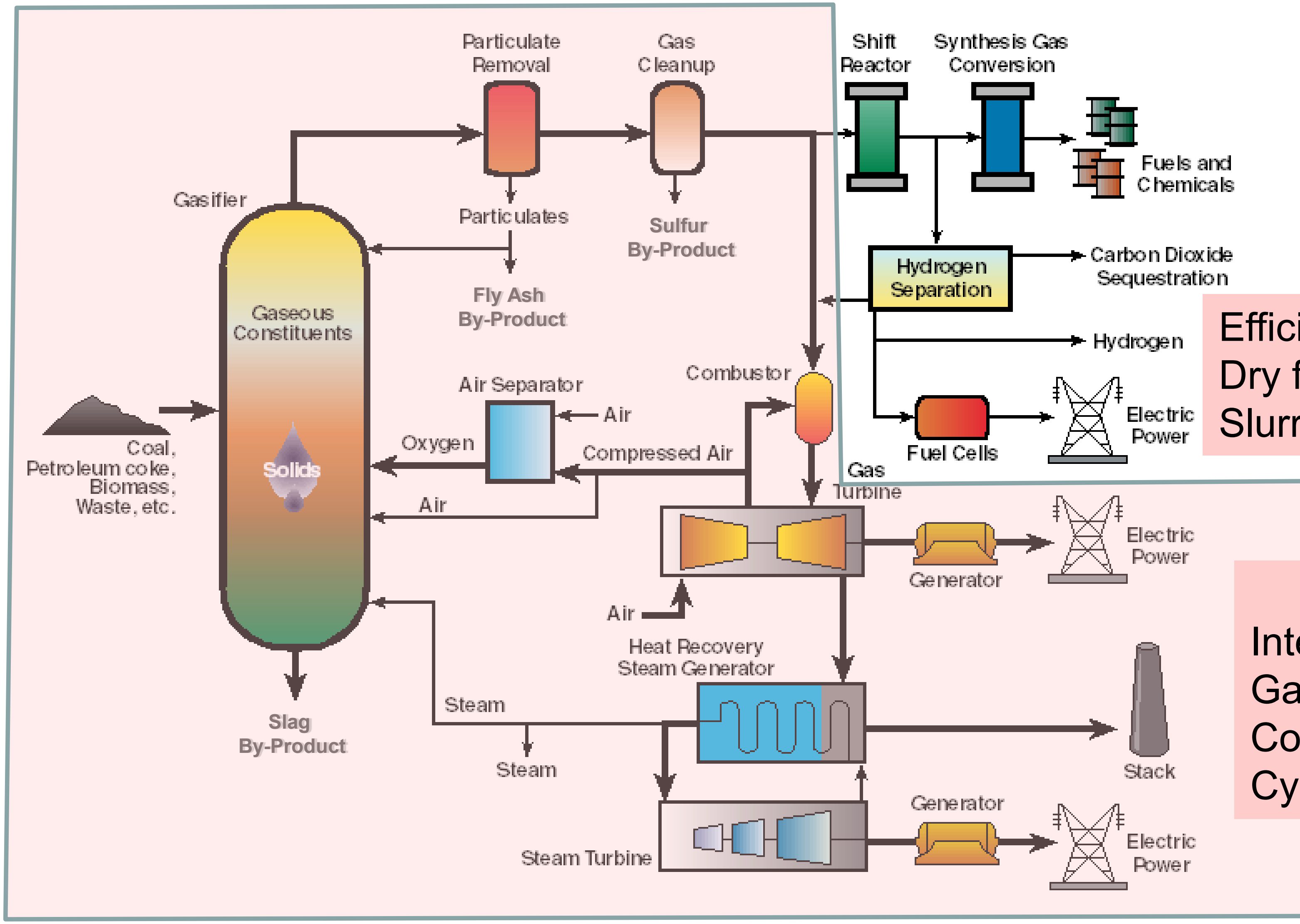


Fig. 1.18 Combustion Engineering IGCC repowering project (published with permission from ref. 31).

What is Oxy-fuel Combustion?



Gasification-Based Energy Production System Concepts

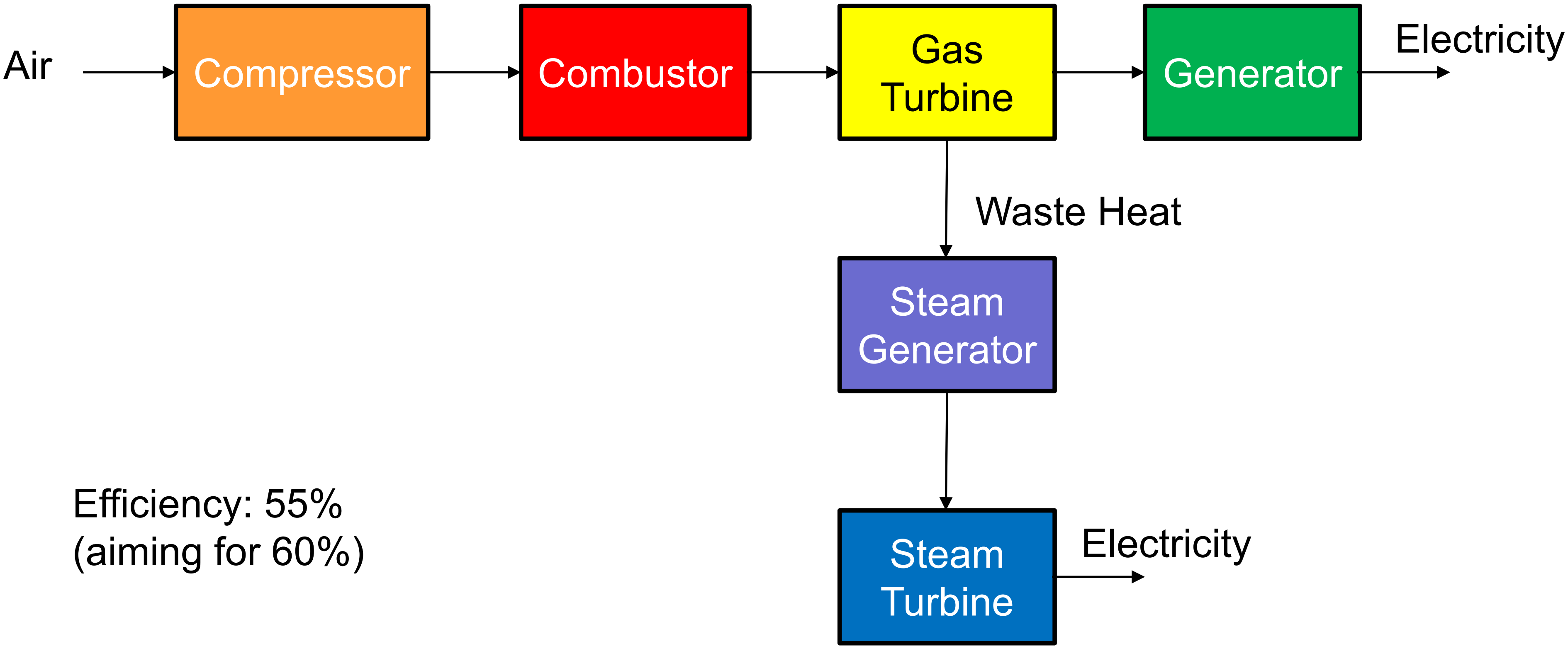


Efficiency:
Dry feed 43%
Slurry feed 38%

<u>IGCC</u>
Integrated
Gasification
Combined
Cycle

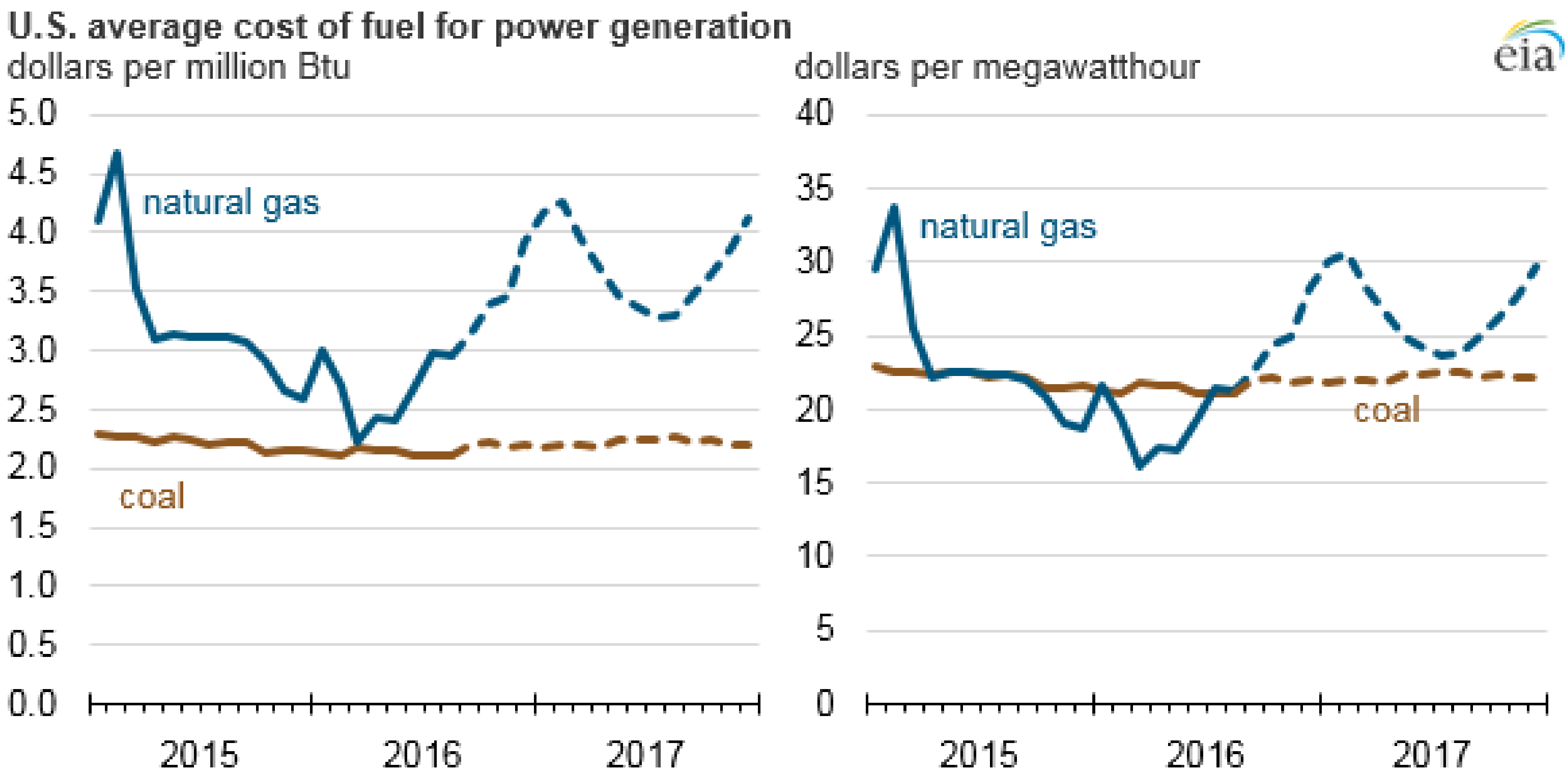
From a presentation by Gary Stiegel, DOE NETL, at the 2006 ACERC Conference

Natural Gas Combined Cycle
(NGCC)



Efficiency: 55%
(aiming for 60%)

Relative Costs



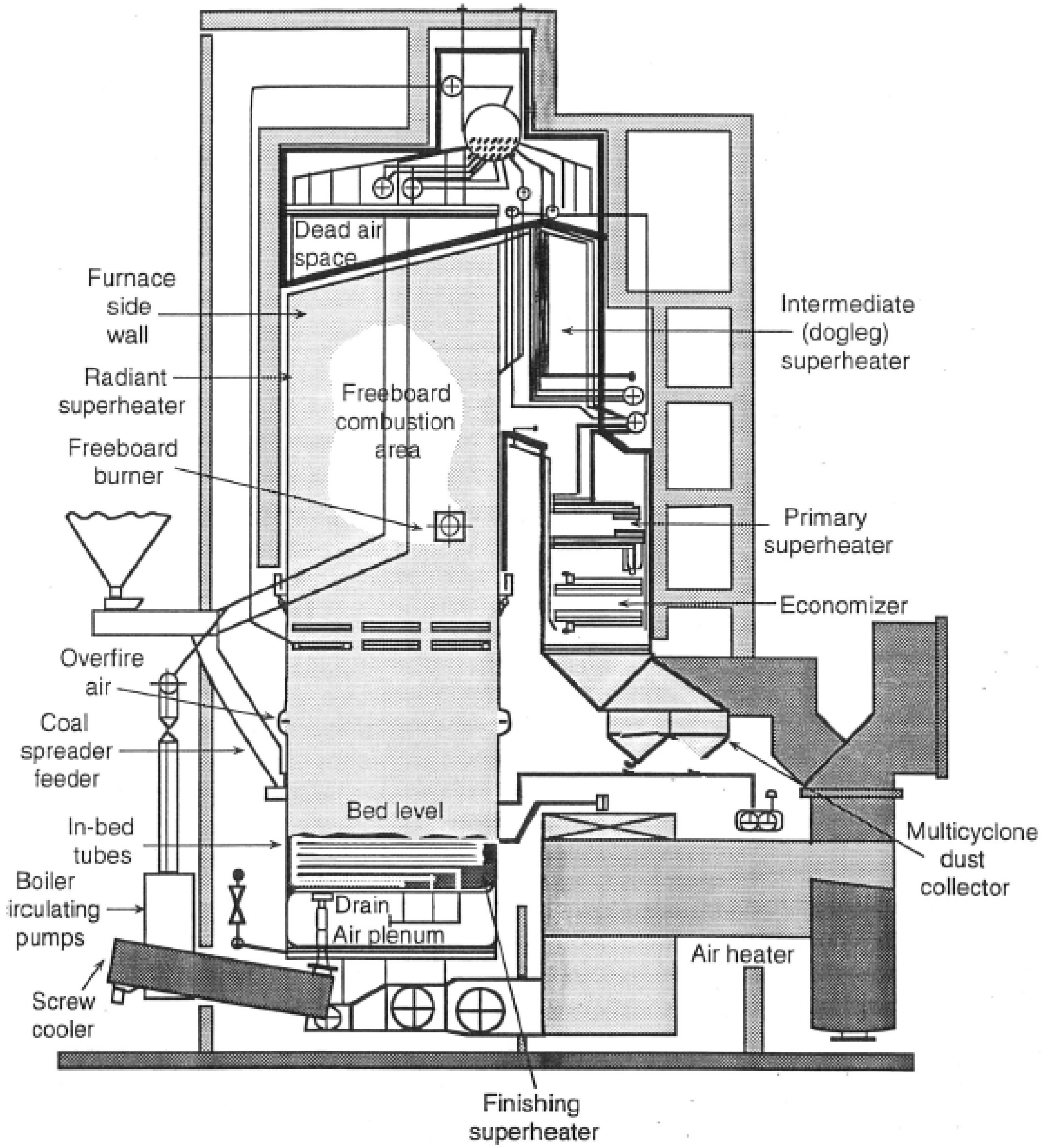


Fig. 1.20 Black Dog bubbling AFBC boiler (published with permission from ref. 50).

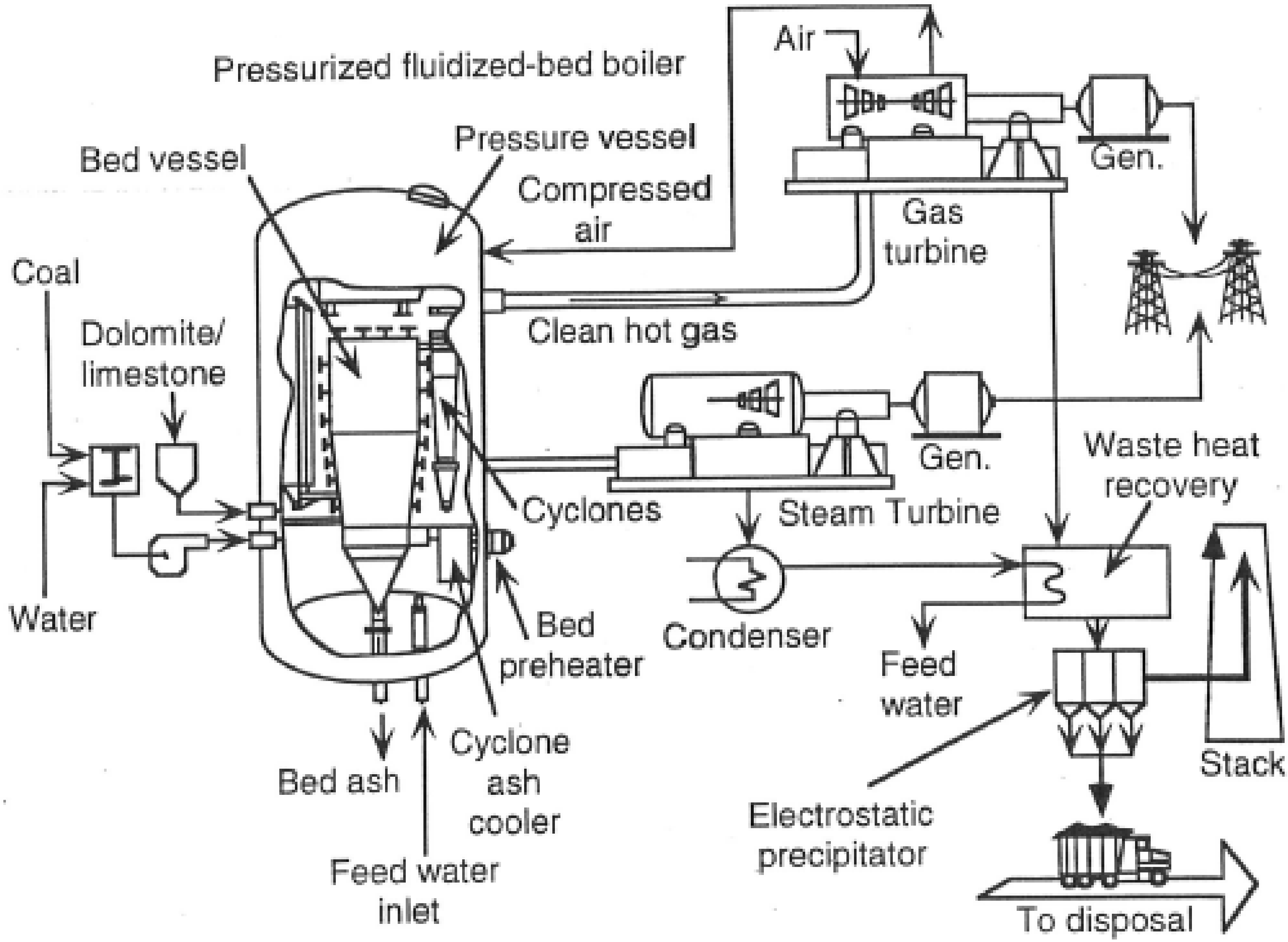


Fig. 1.22 Tidd PFBC demonstration project (published with permission from ref. 31).

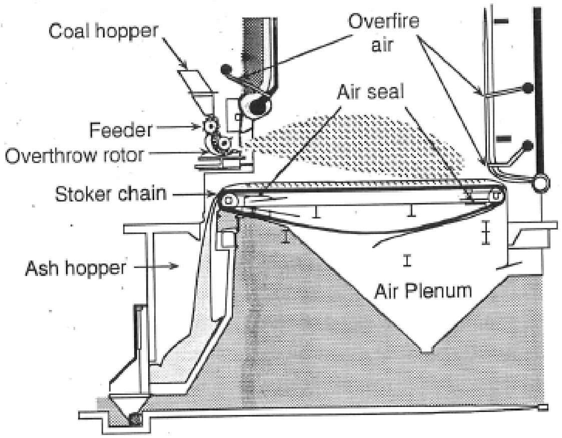


Fig. 1.26 Traveling grate spreader stoker (published with permission from ref. 35).

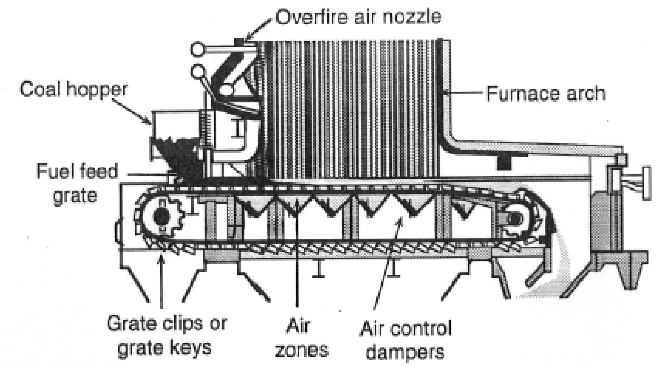


Fig. 1.27 Traveling grate overfeed stoker (published with permission from ref. 56).

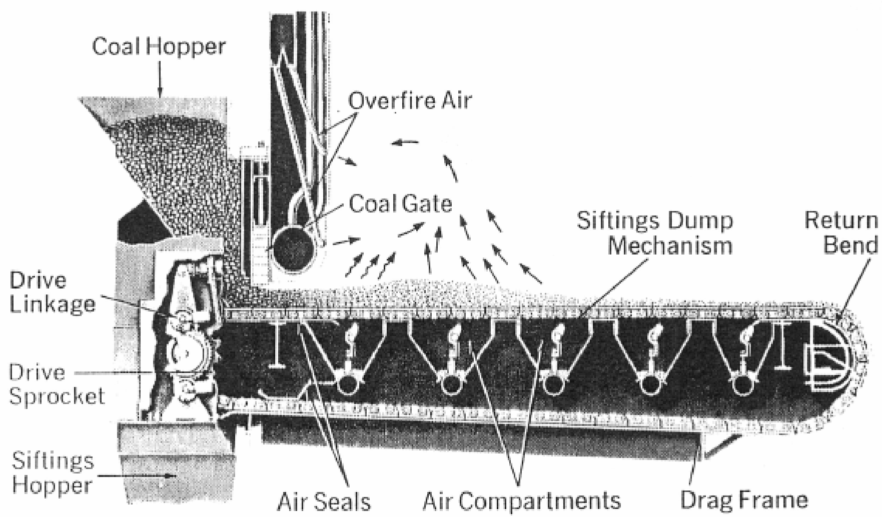


Fig. 9 Chain-grate stoker. (*Courtesy Laclede Stoker Co.*)

Medium Coal Feed Rate
(1.5 to 20 tons/hr)

High Coal Feed Rate
(20 to 105 tons/hr)

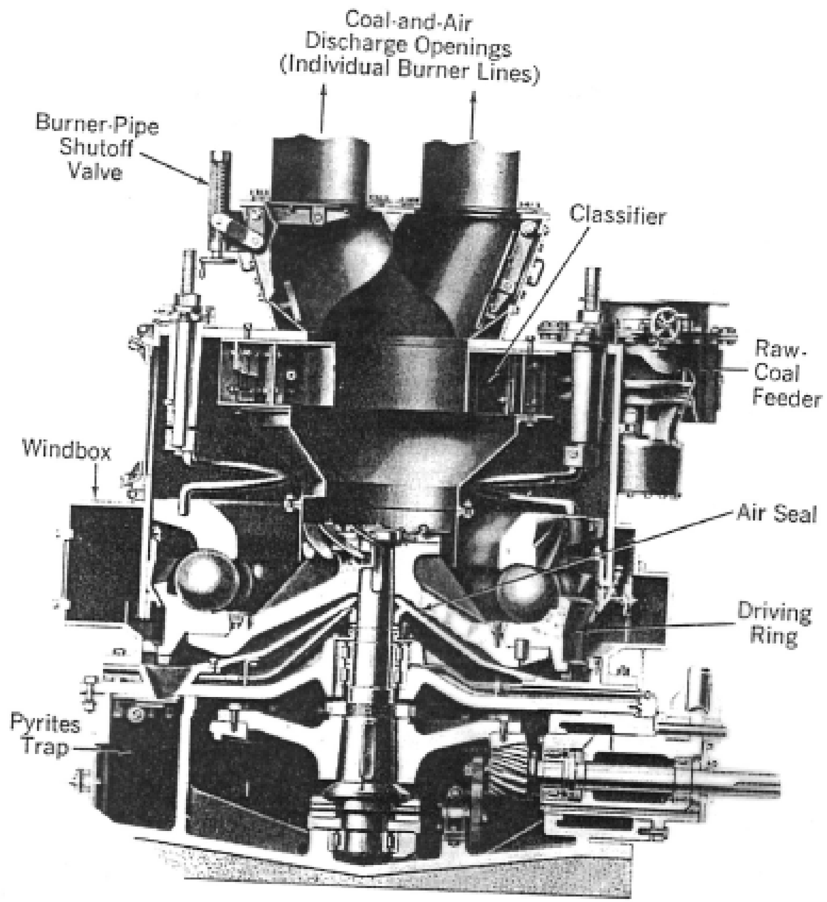


Fig. 7 B&W Type EL single-row ball-and-race pulverizer.

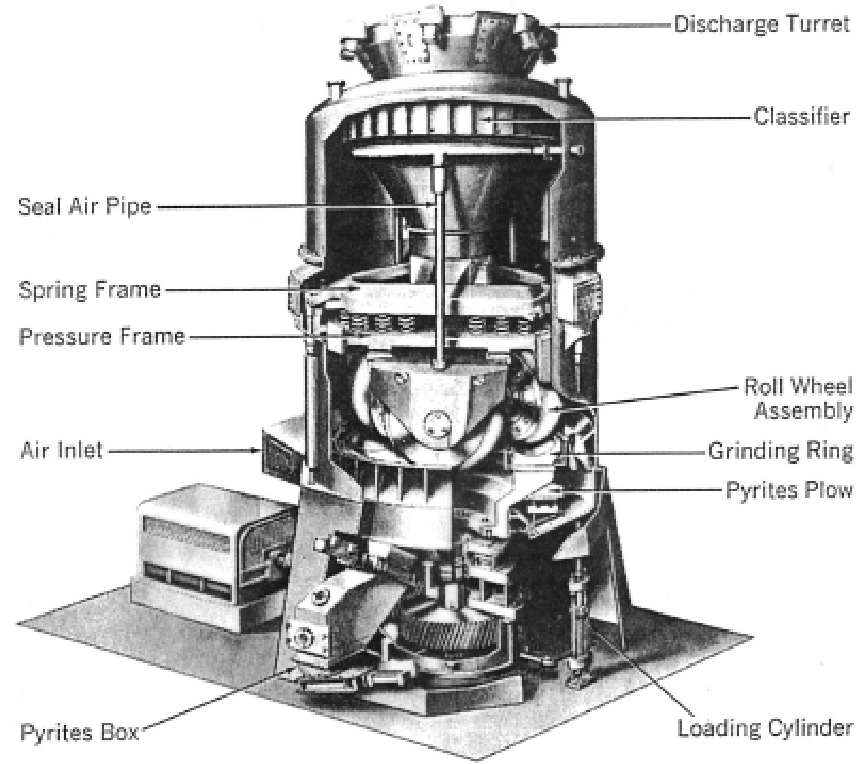


Fig. 8 Babcock & Wilcox Type MPS mill.

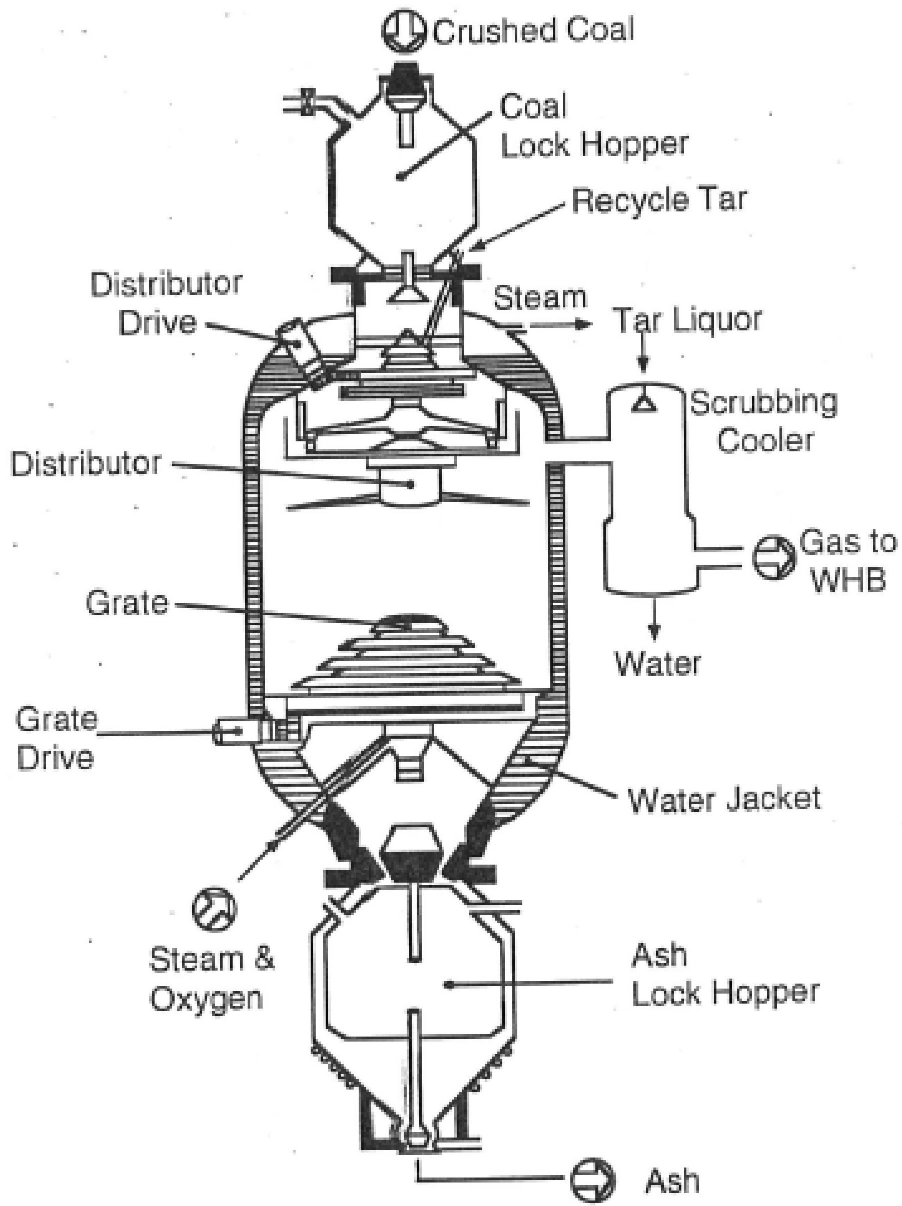


Fig. 1.29 Dry-ash Lurgi gasifier (published with permission from ref. 62).

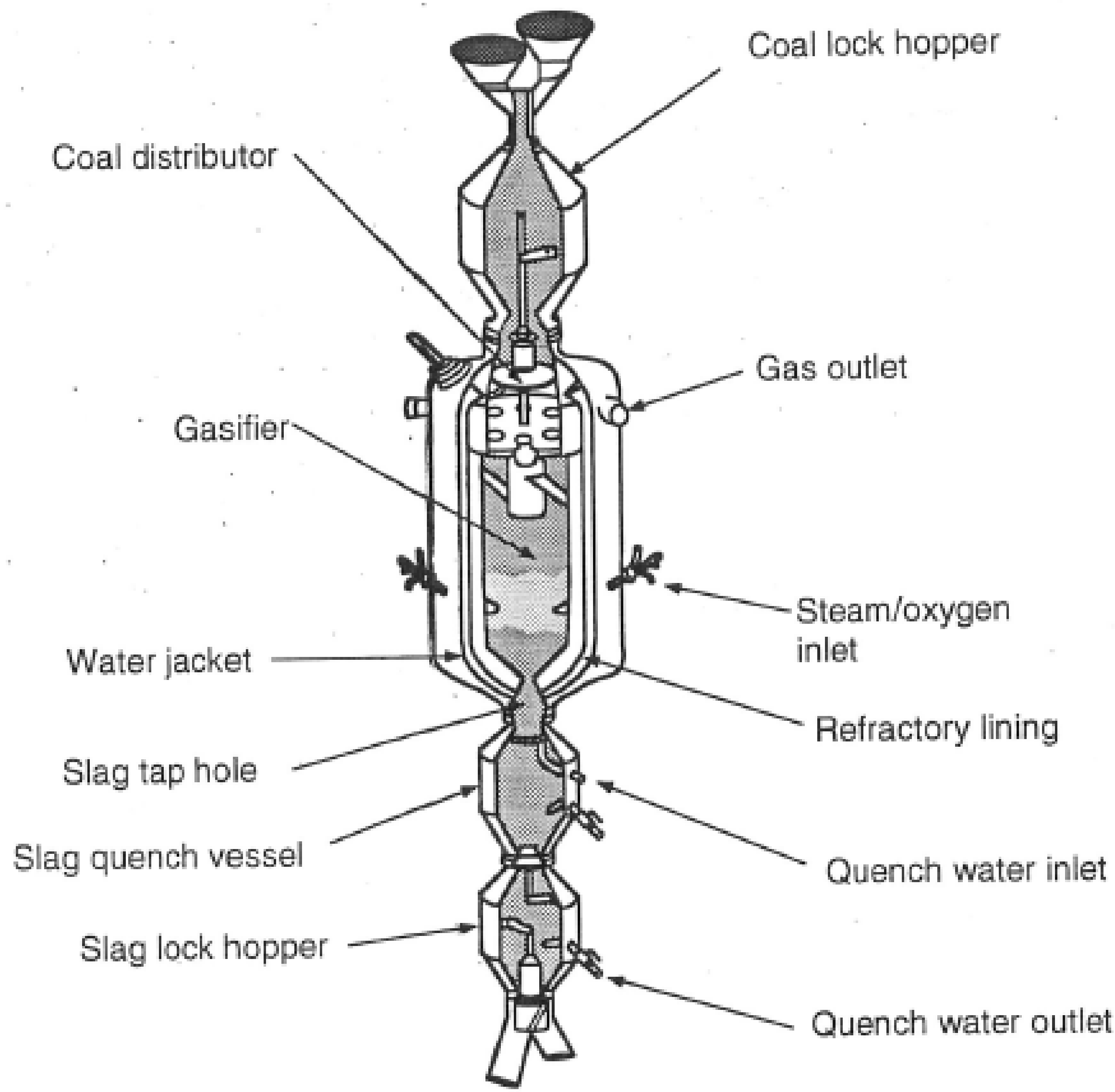


Fig. 1.30 British Gas Corporation/Lurgi slagging gasifier (published with permission from ref. 28).

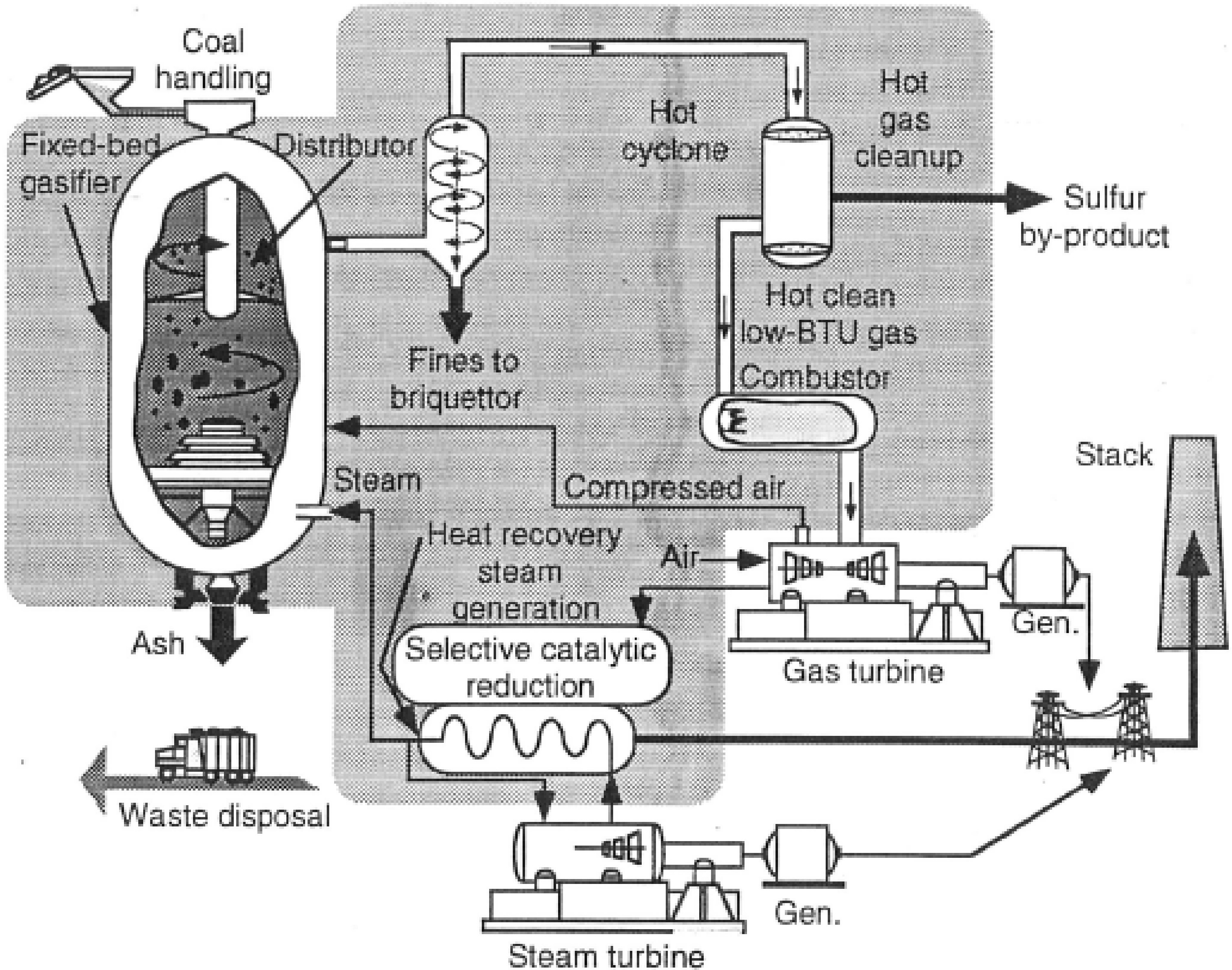


Fig. 1.31 Air-blown/integrated gasification combined-cycle project (published with permission from ref. 31).

4. Where Does The Ash Go?

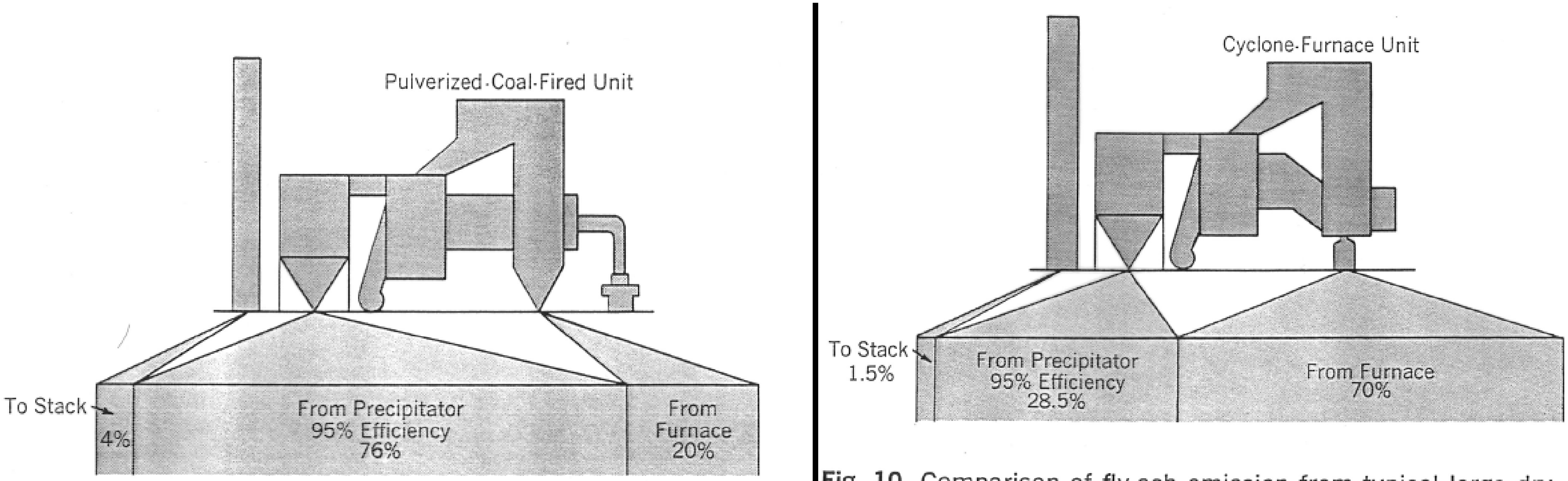


Fig. 10 Comparison of fly-ash emission from typical large dry-ash removal pulverized-coal-fired unit and Cyclone-Furnace unit.

5. Co-firing Biomass

- Lower fuel costs
- More CO_2 friendly

- Changes deposit properties
  - Perhaps vaporization of Na, K, HCl
- Size of biomass?
- Supply of biomass
- Ash disposal regulations
- Risk
- Separate biomass handling system
  - Spontaneous ignition of biomass pile
- Lower heating value of biomass
- Possible increase in PM

Interesting Stuff

Heat Transfer

Mineral matter in coal and the thermal performance of large boilers

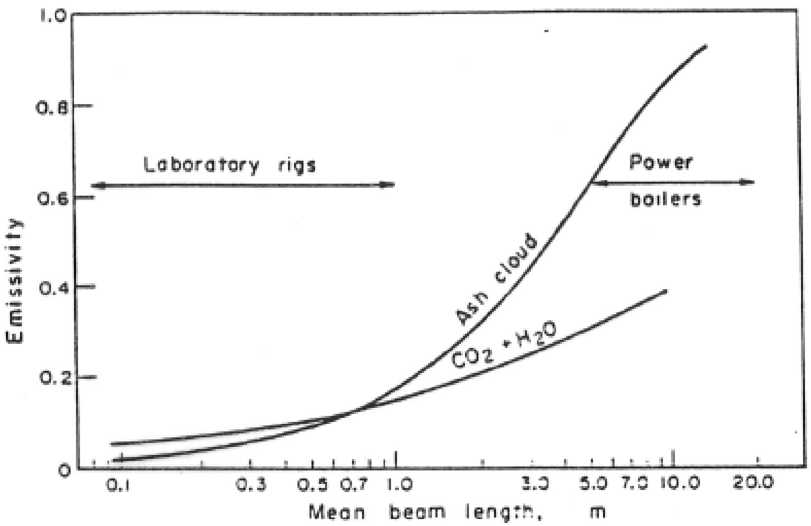


FIG. 3. Emissivity of p.f. combustion product components.

TABLE 11. Effect of ash absorption area on heat absorbed in furnace[66]

Ash cloud absorption area (m^2/kg)	Mean particle absorption efficiency	Heat absorbed in furnace (MW)
58.4	0.7	362.5
41.7	0.5	338.9
10.4	0.125	271.8

from Wall et al., PECS, 5, 1-29 (1979)

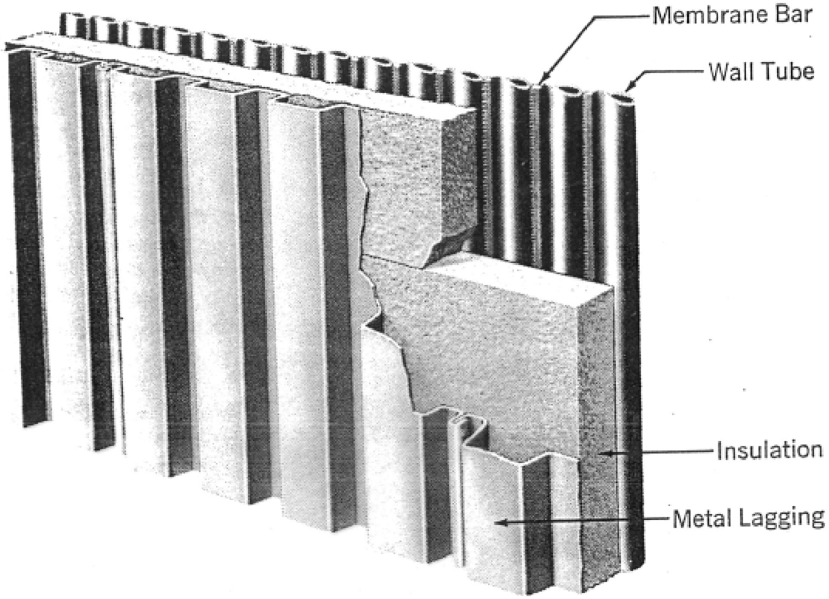


Fig. 2 Membrane wall construction.

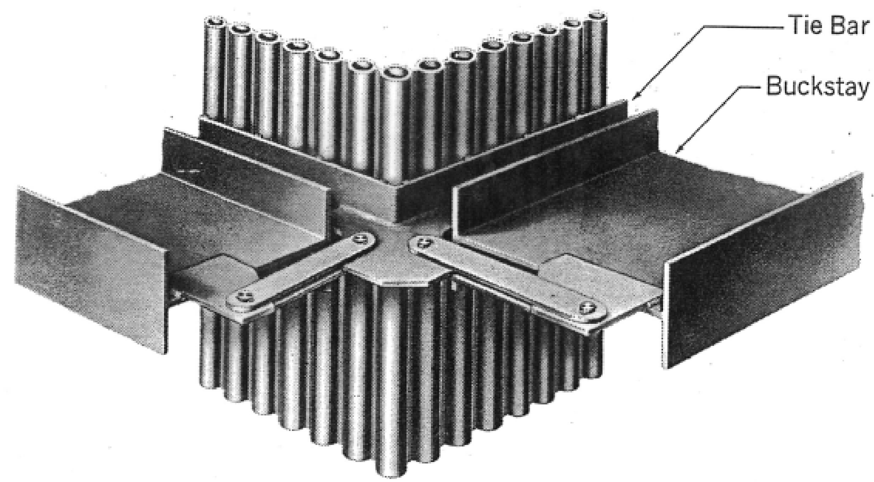


Fig. 6 Tie bar and buckstay arrangement at corner of furnace.

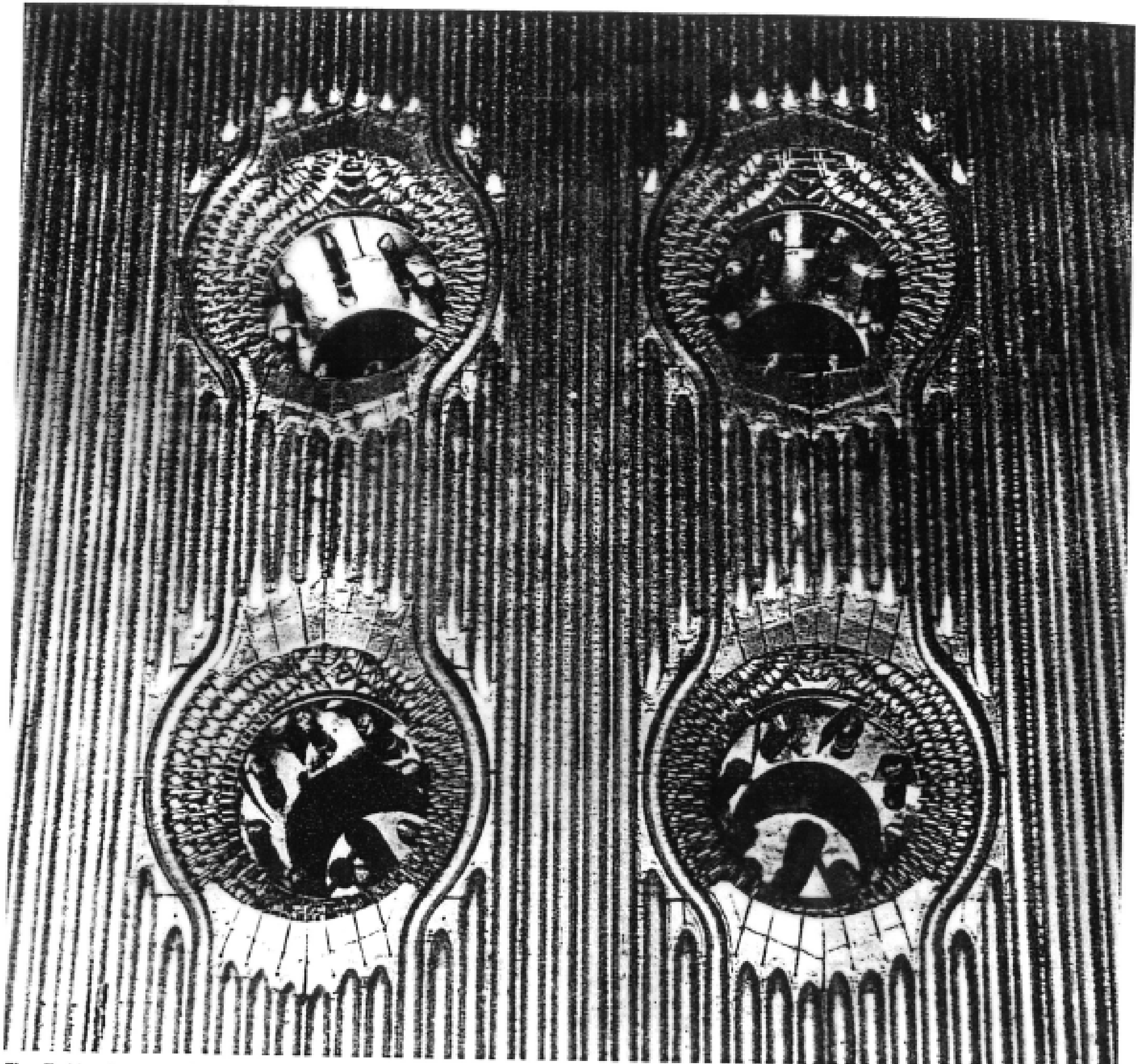
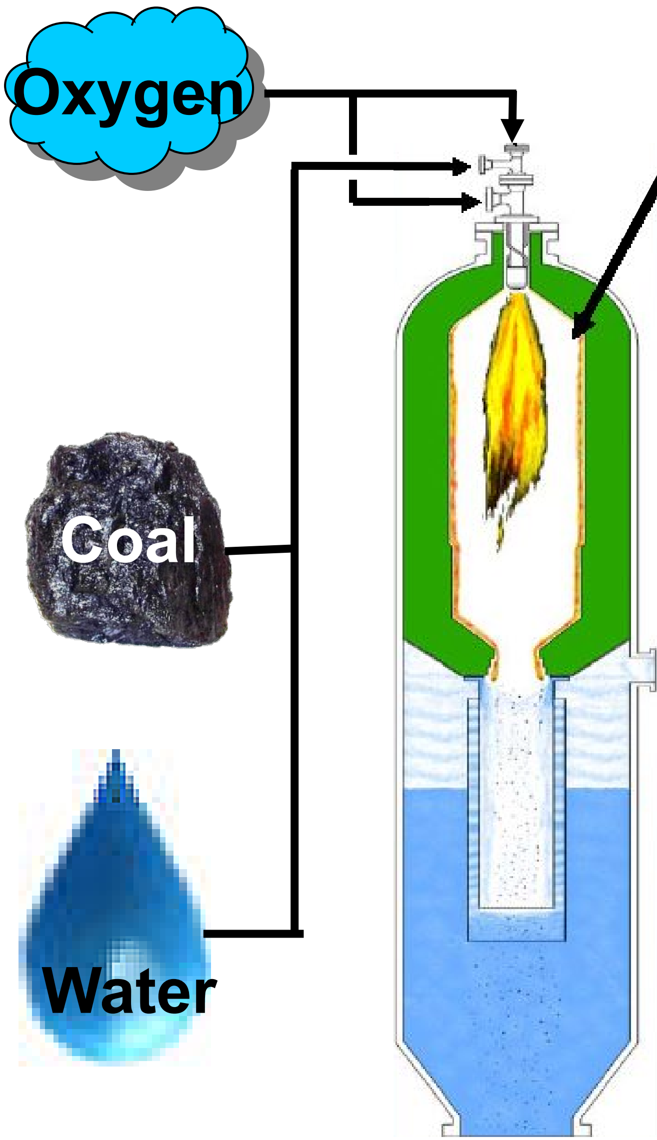


Fig. 7 Membrane-wall construction applied to a burner wall.

What is Gasification?



Extreme Conditions:

- **1,000 psig or more**
- **2,600 Deg F**
- **Corrosive slag and H_2S gas**

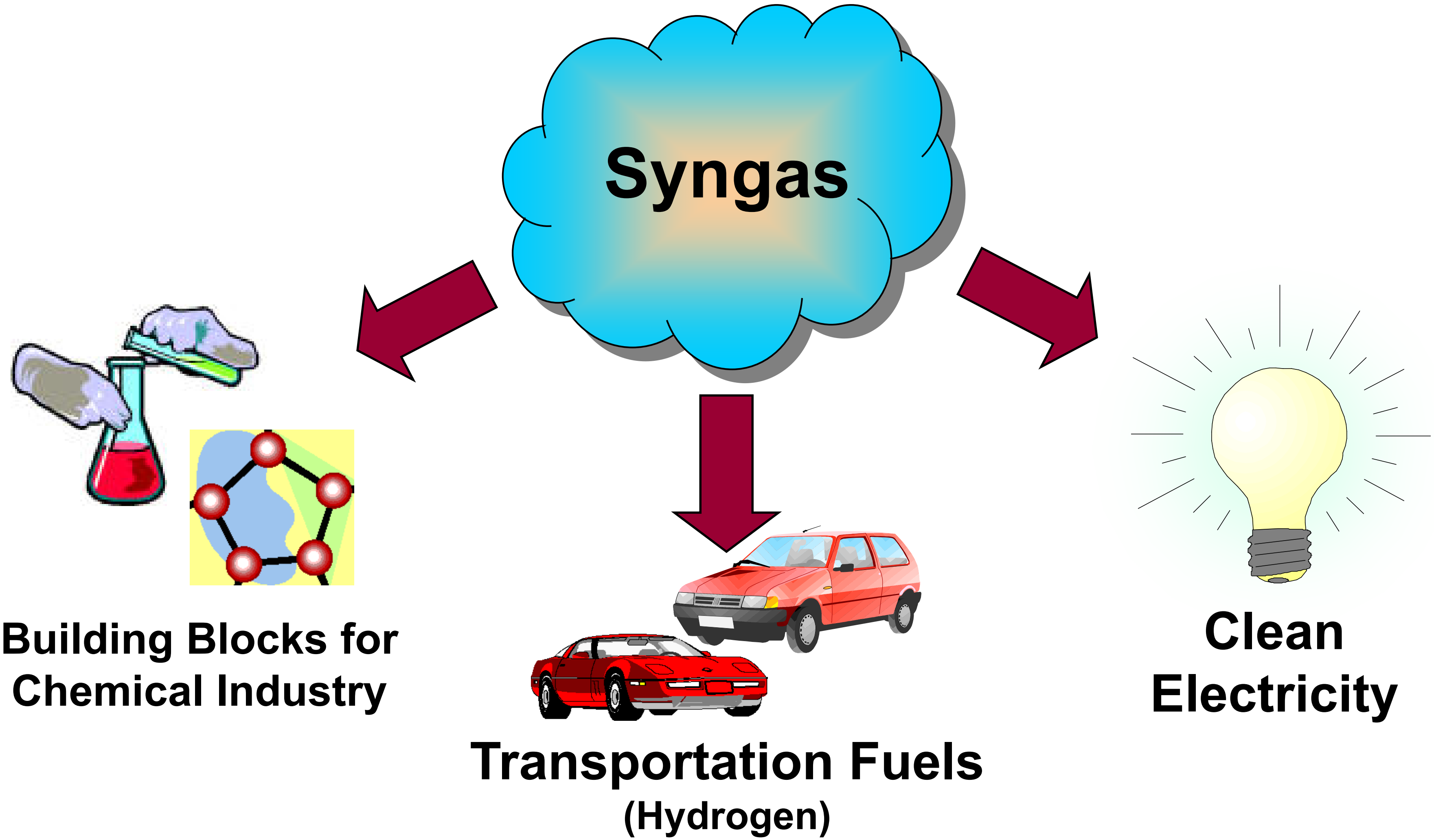
Products (syngas)
CO (Carbon Monoxide)
H_2 (Hydrogen)
[CO/H_2 ratio can be adjusted]

By-products
H_2S (Hydrogen Sulfide)
CO_2 (Carbon Dioxide)
Slag (Minerals from Coal)

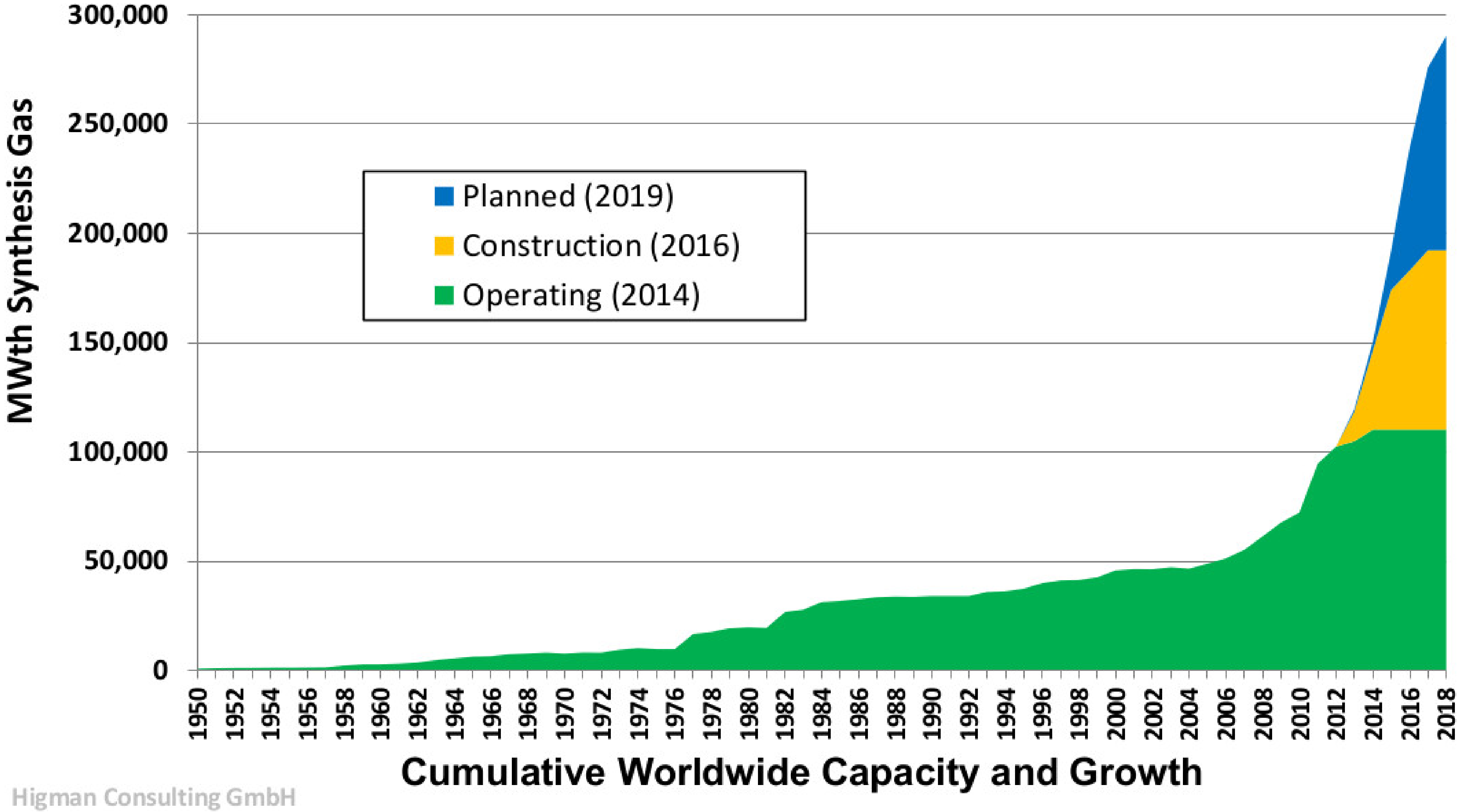
Gas Clean-Up Before Product Use

courtesy Gary Stiegel, DOE NETL, talk at ACERC conf. (2006)

So what can you do with CO and H_2 ?

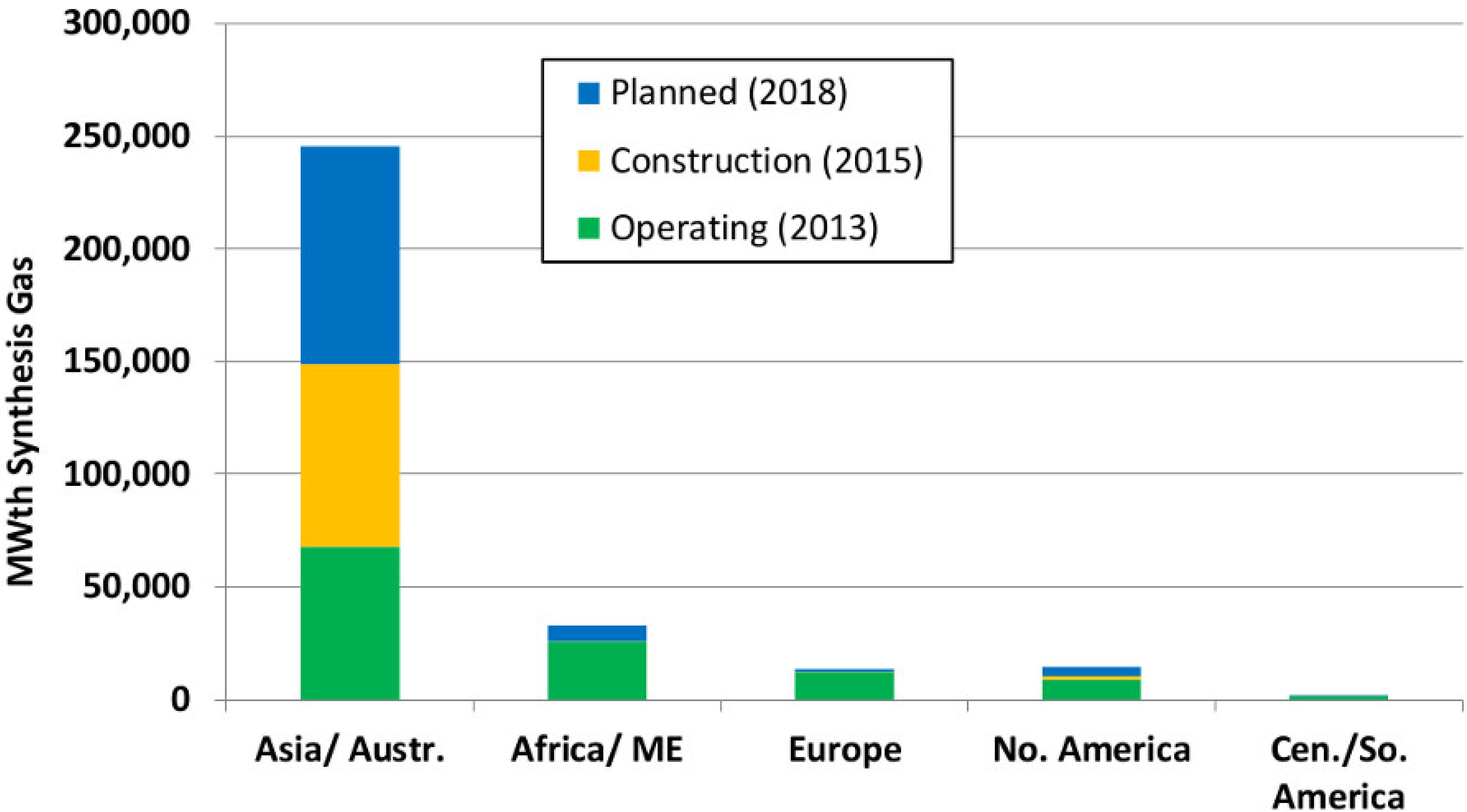


courtesy Gary Stiegel, talk at ACERC conf. (2006)



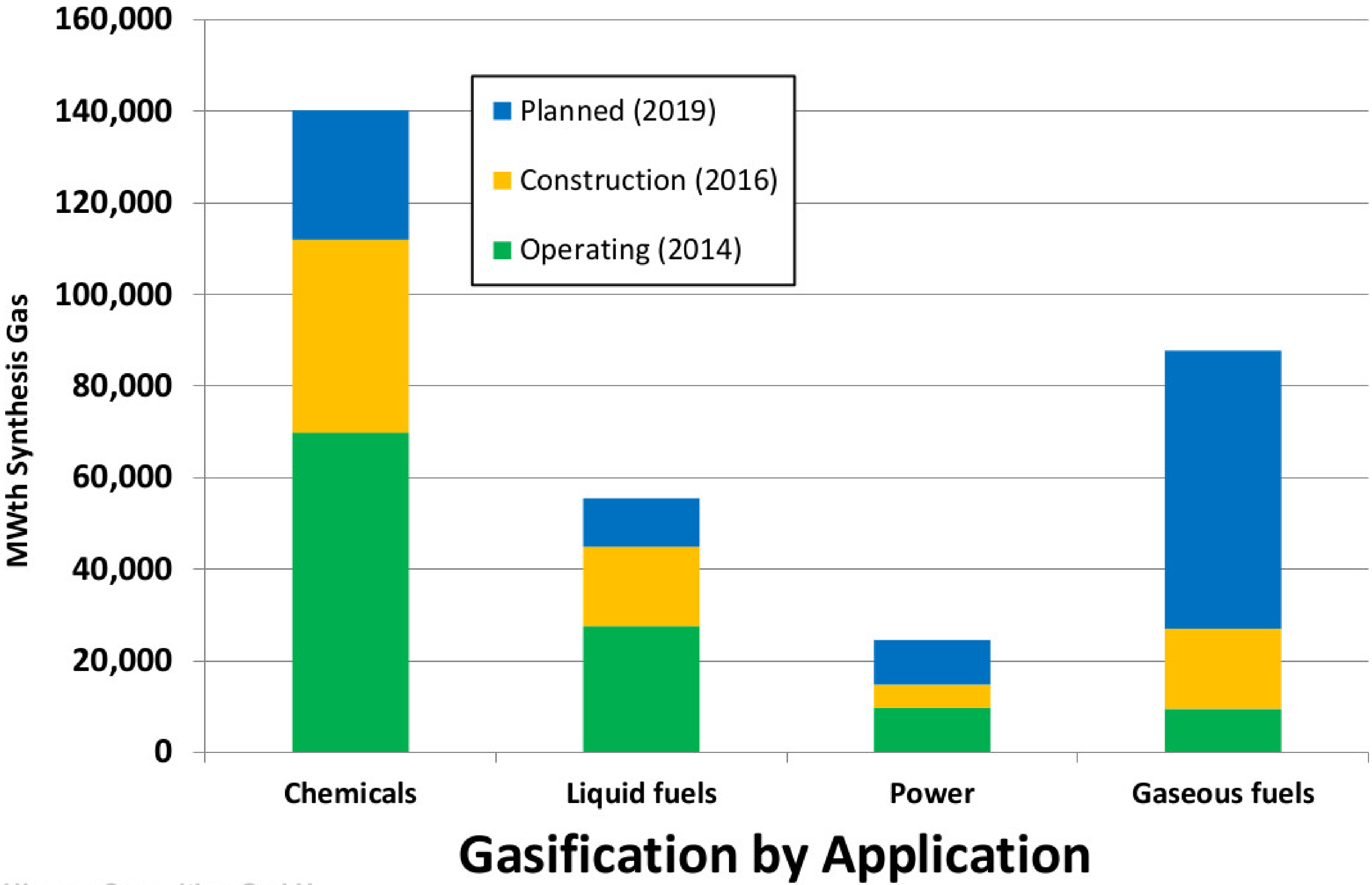
http://www.gasification-syngas.org/resources/the-gasification-industry/

Gasification by Region

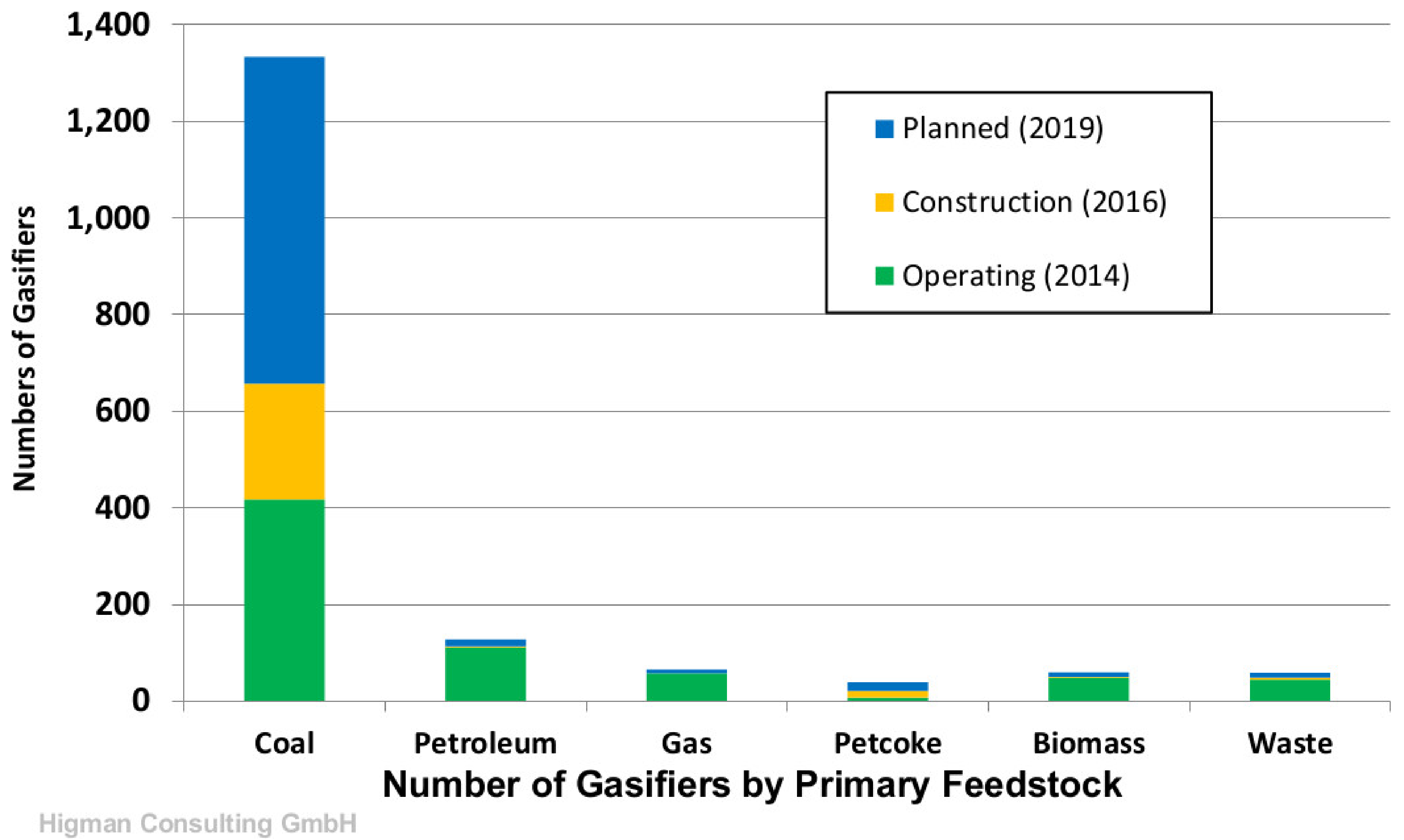


Gasification Capacity by Geographic Region

Higman Consulting GmbH



Higman Consulting GmbH


1,400
1,200
1,000
800
600
400
200
0
Numbers of Gasifiers
Planned (2019)
Construction (2016)
Operating (2014)
Coal
Petroleum
Gas
Petcoke
Biomass
Waste
Number of Gasifiers by Primary Feedstock
Higman Consulting GmbH

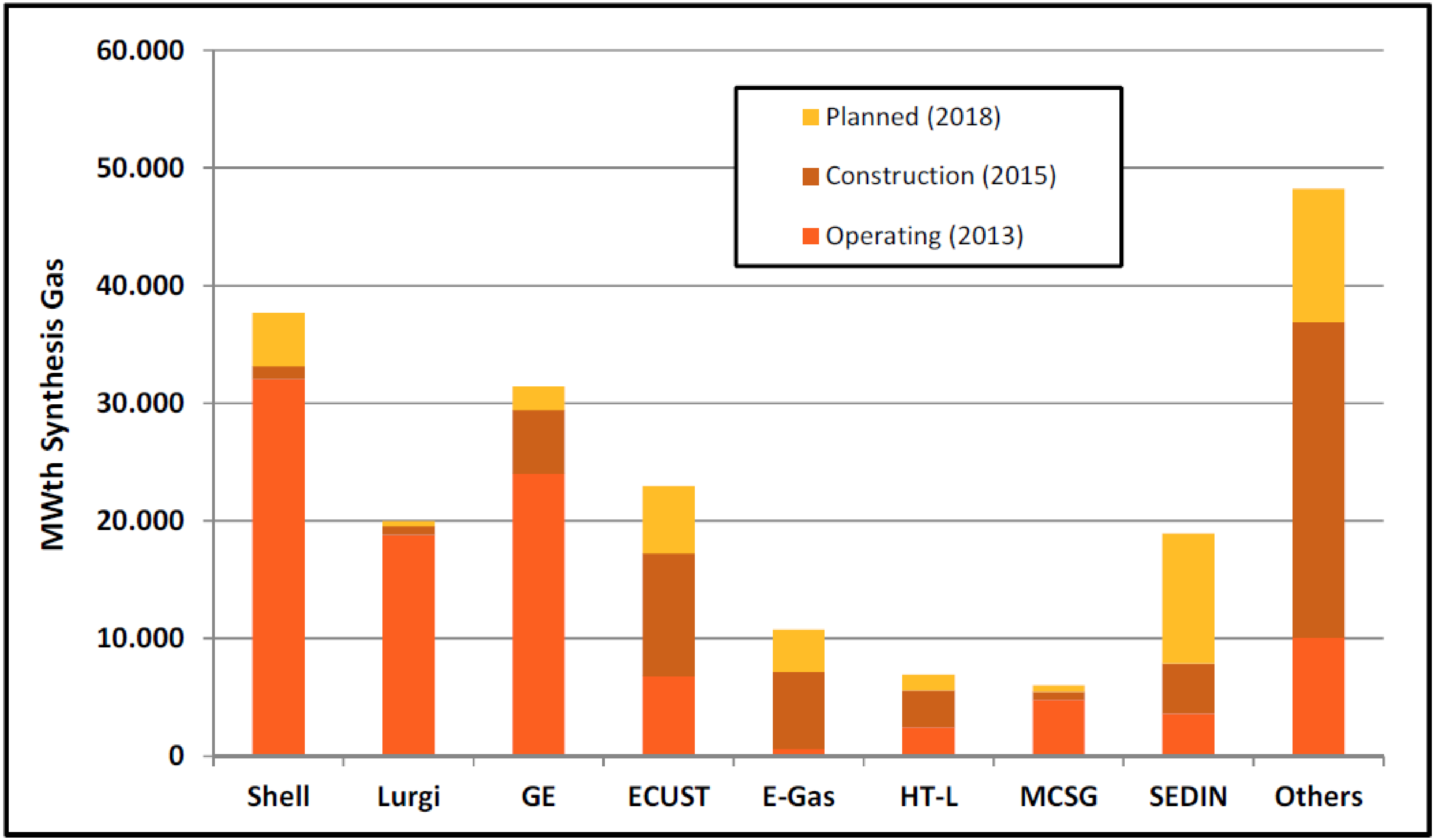
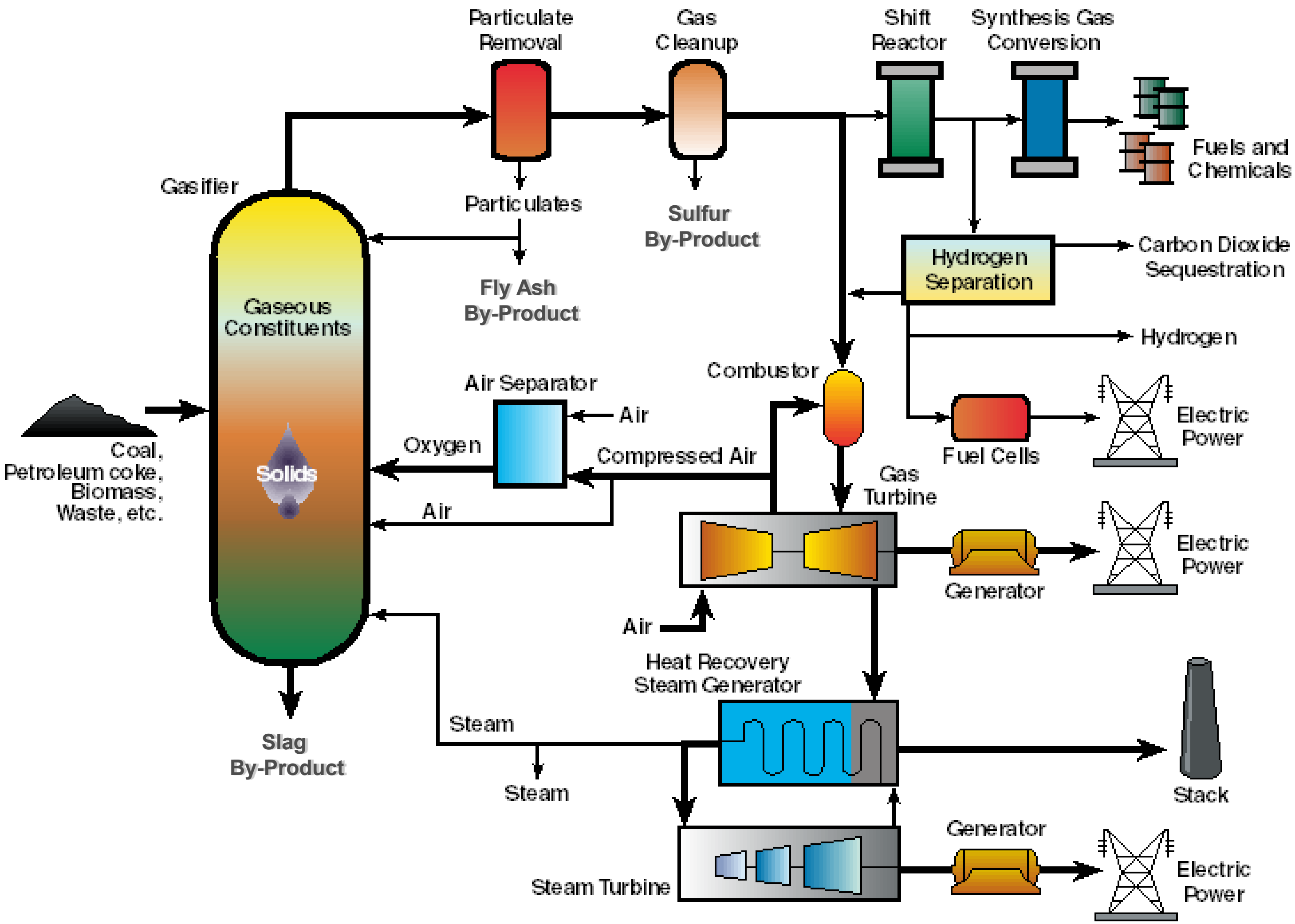


Figure 8 **Gasification by Technology**

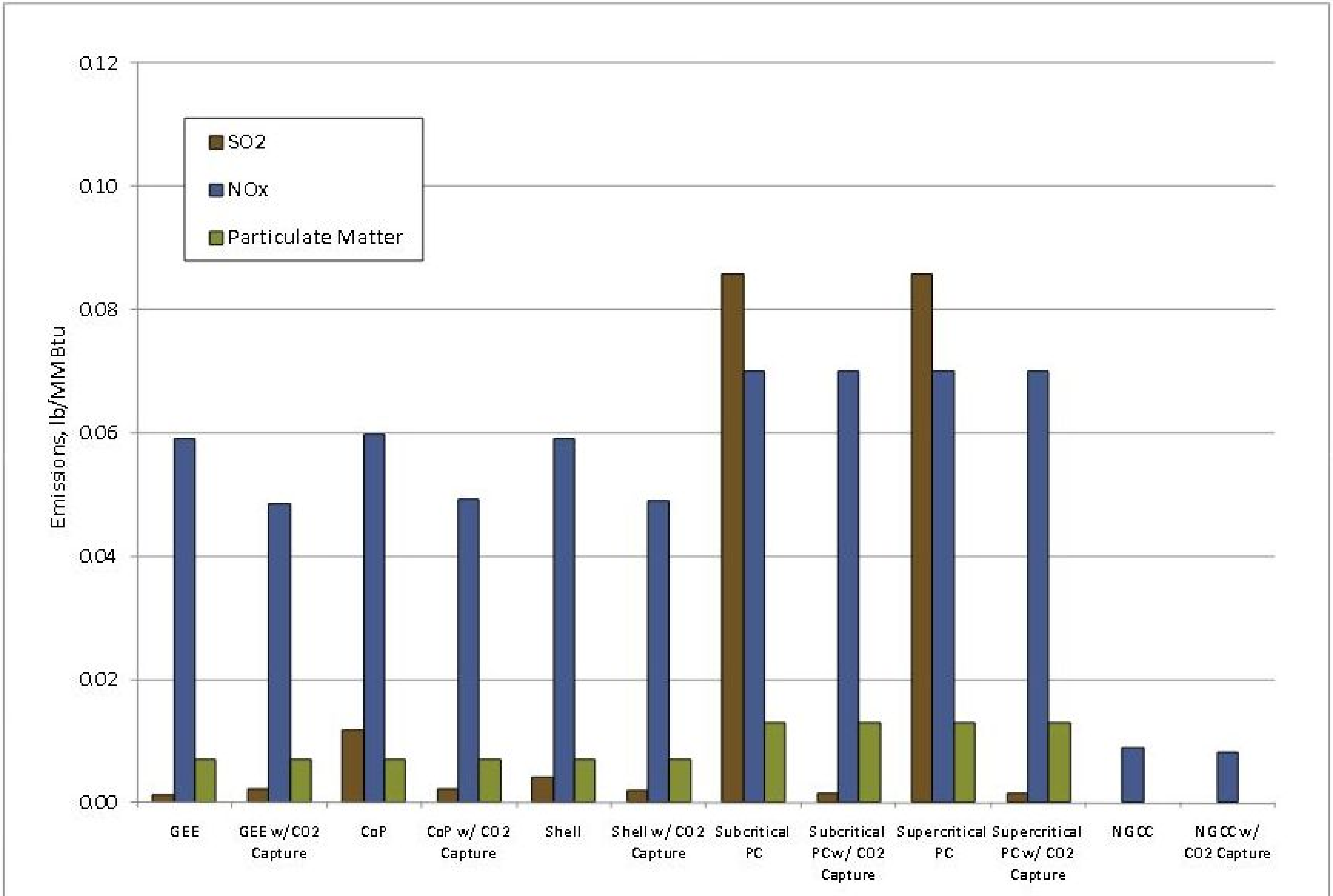
Higman, Pittsburgh Coal Conference, Beijing, China (Sept., 2013)

Gasification-Based Energy Production System Concepts

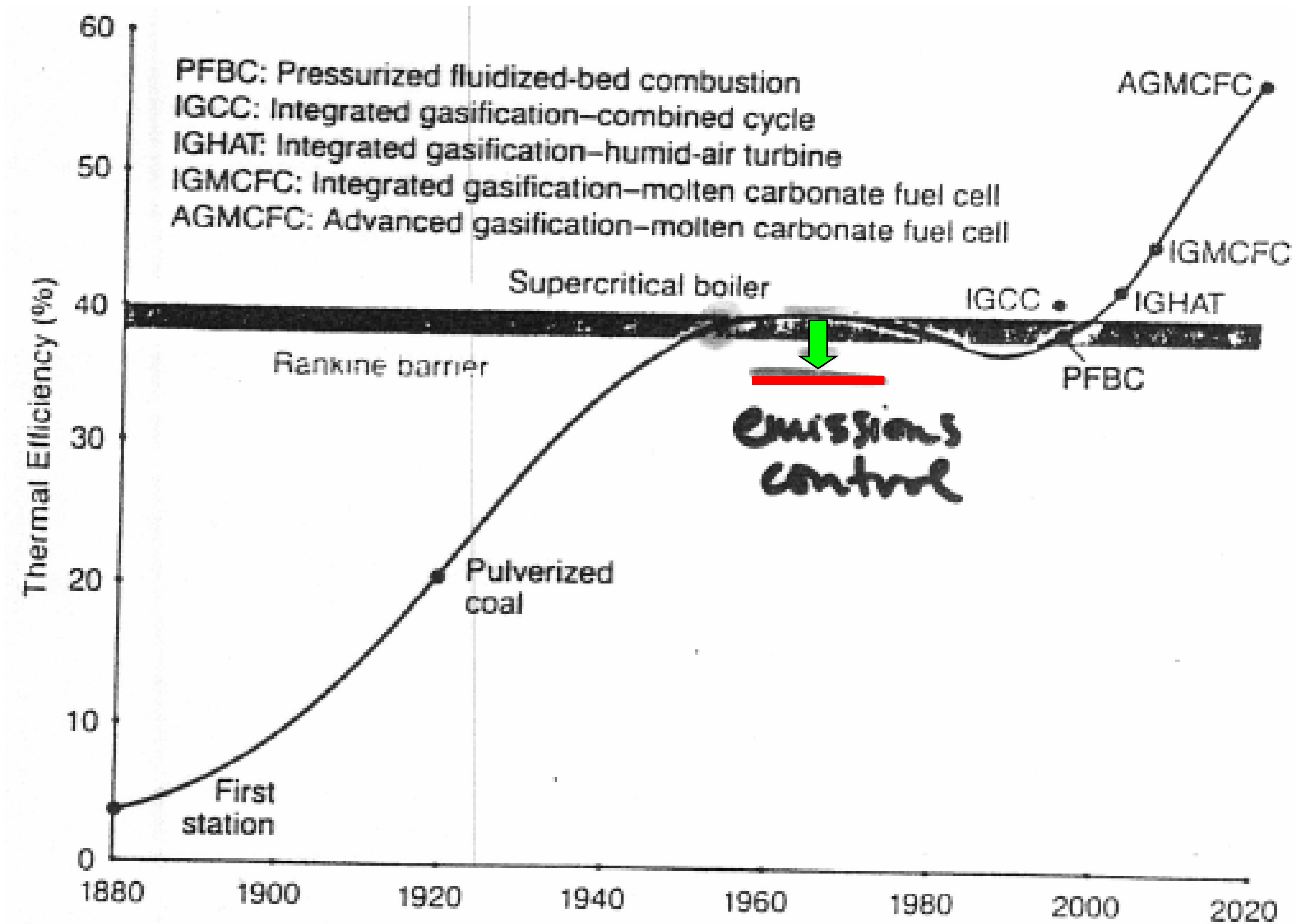


courtesy Gary Stiegel, talk at ACERC conf. (2006)

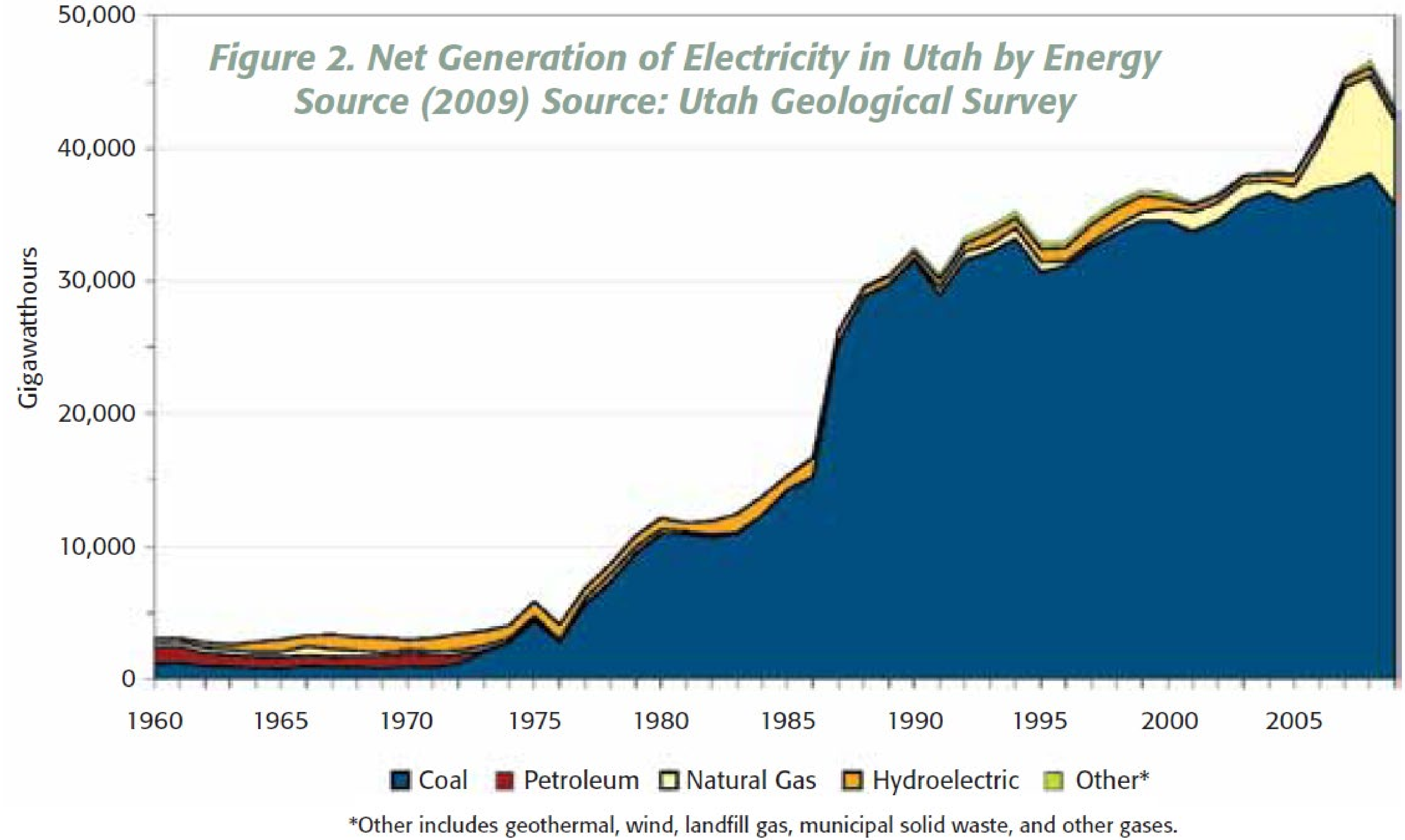
Compare Emissions



From Wikipedia

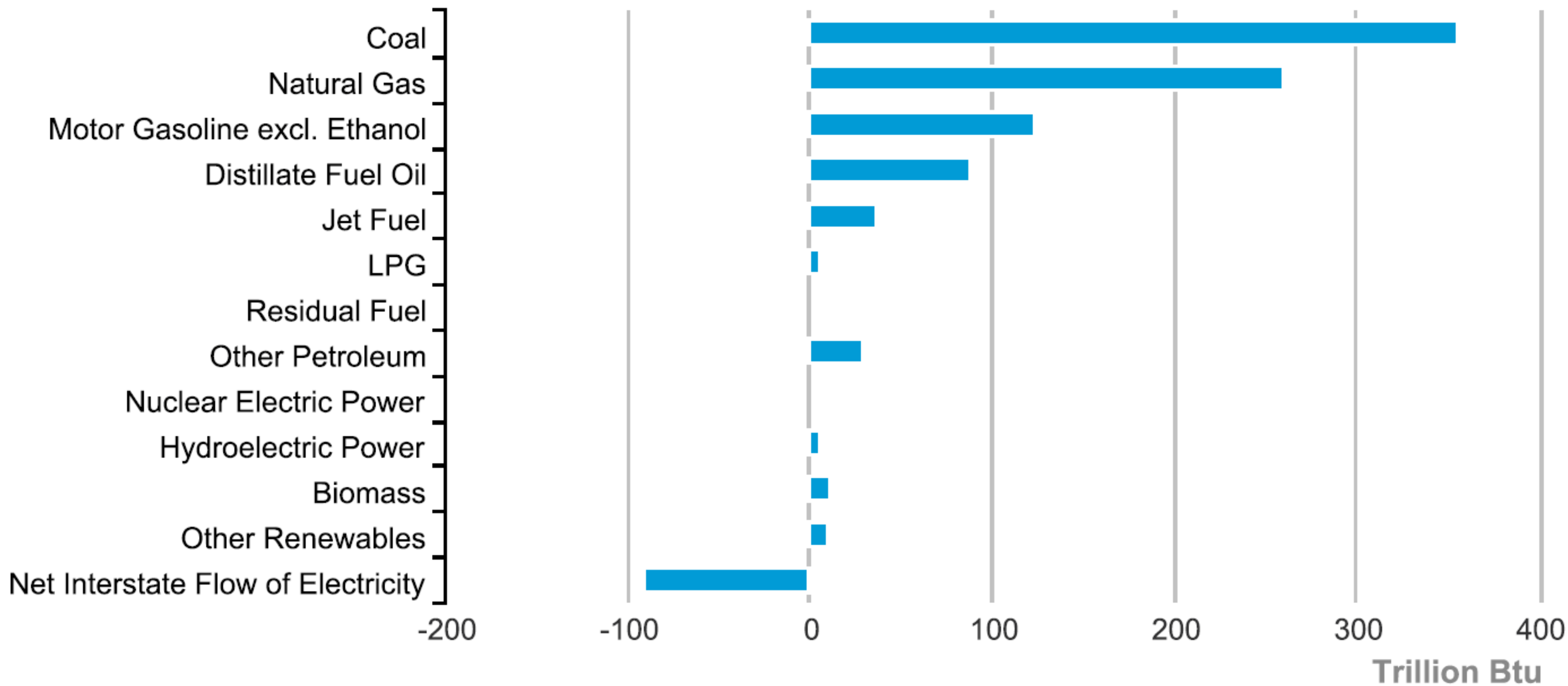


J. Douglas, "Breaking Through the Performance Limits and Beyond Steam," EPRI Journal, pp. 4-11 (Dec. 1990)



From "Energy Initiatives and Imperatives: Utah's 10-Year Strategic Energy Plan," Governor Gary R. Herbert (March 2, 2011)

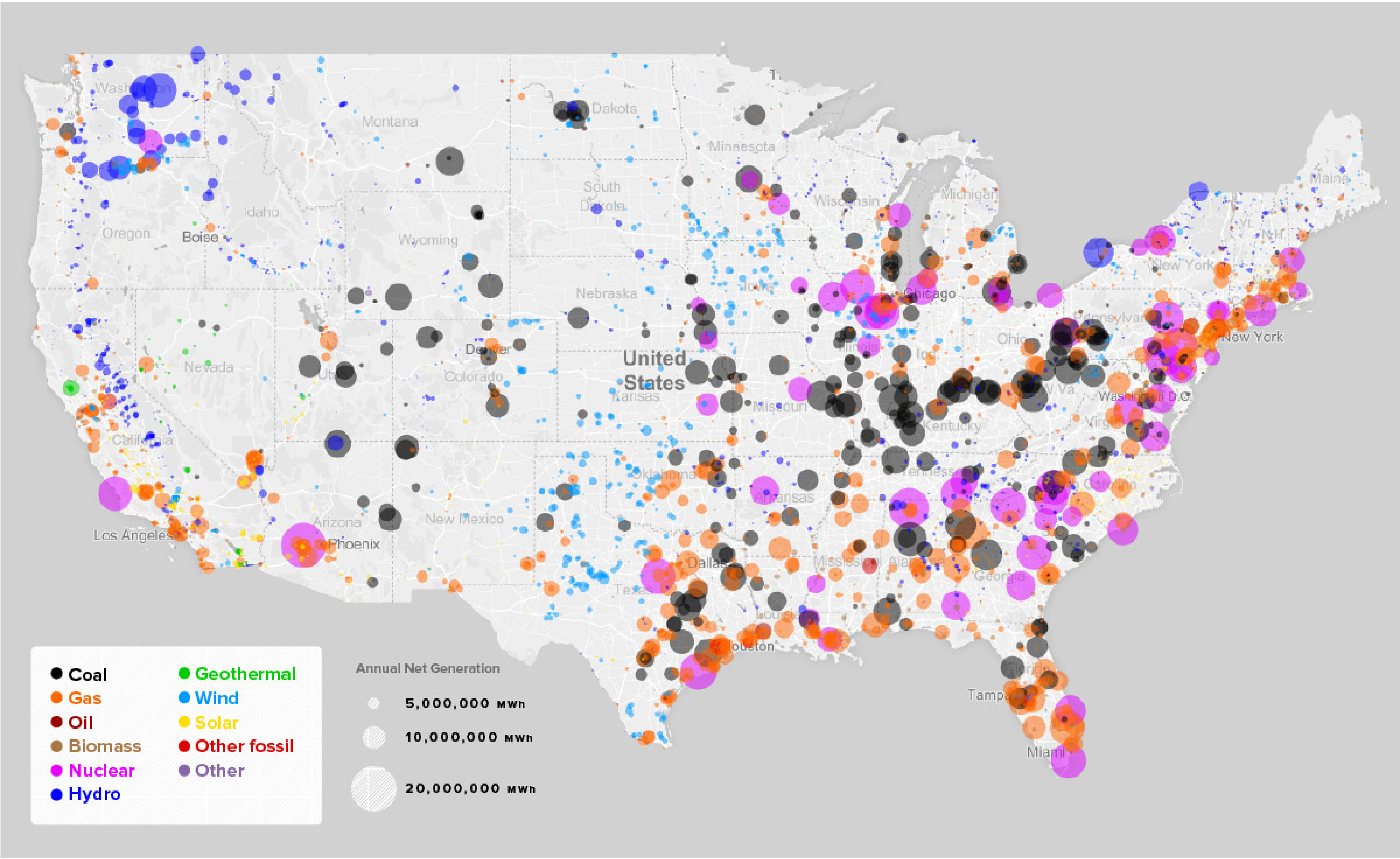
Utah Energy Consumption Estimates, 2013



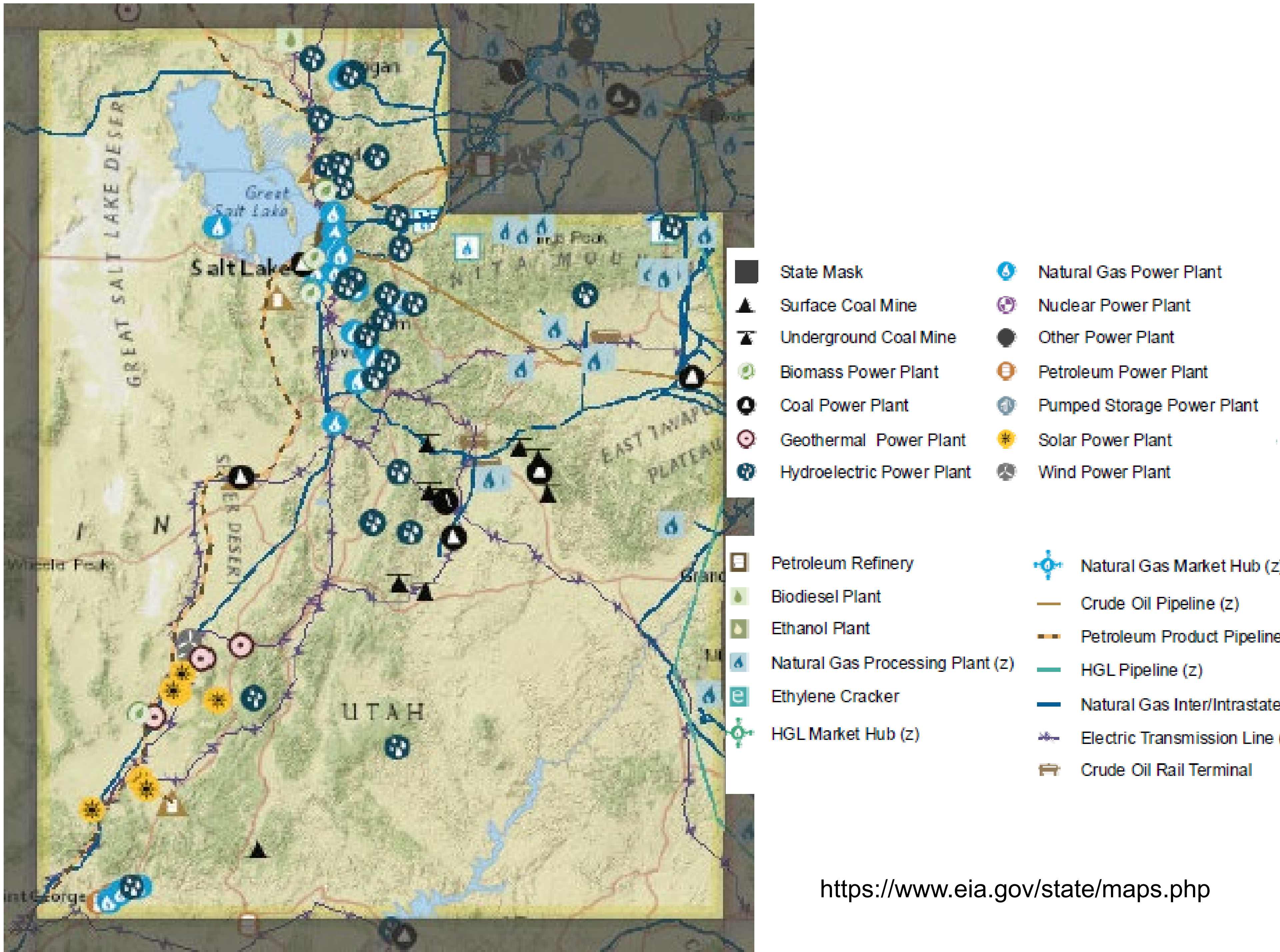
Source: Energy Information Administration, State Energy Data System

http://www.eia.gov/state/?sid=UT

U.S. Power Plants

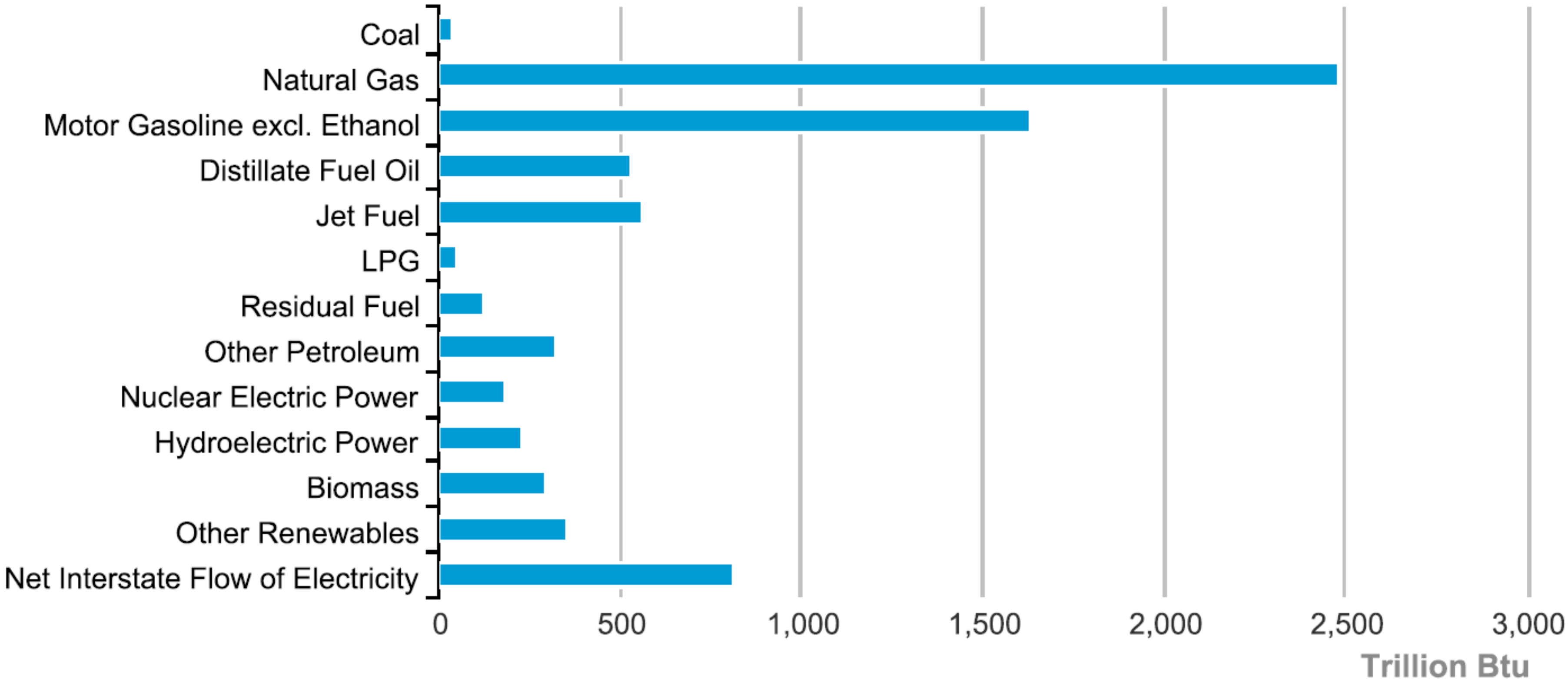


https://www.visualcapitalist.com/mapped-every-power-plant-in-the-united-states/

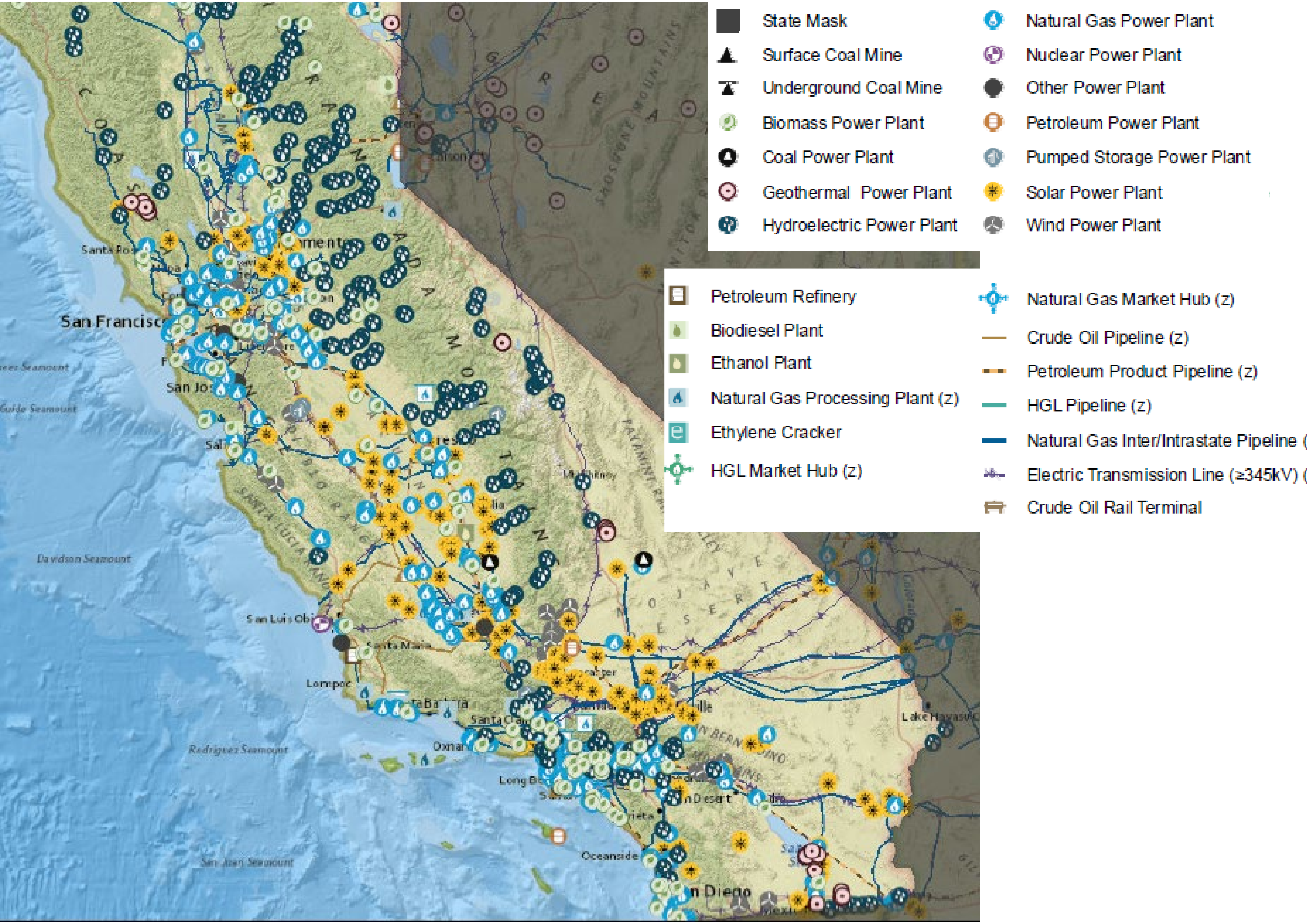


https://www.eia.gov/state/maps.php

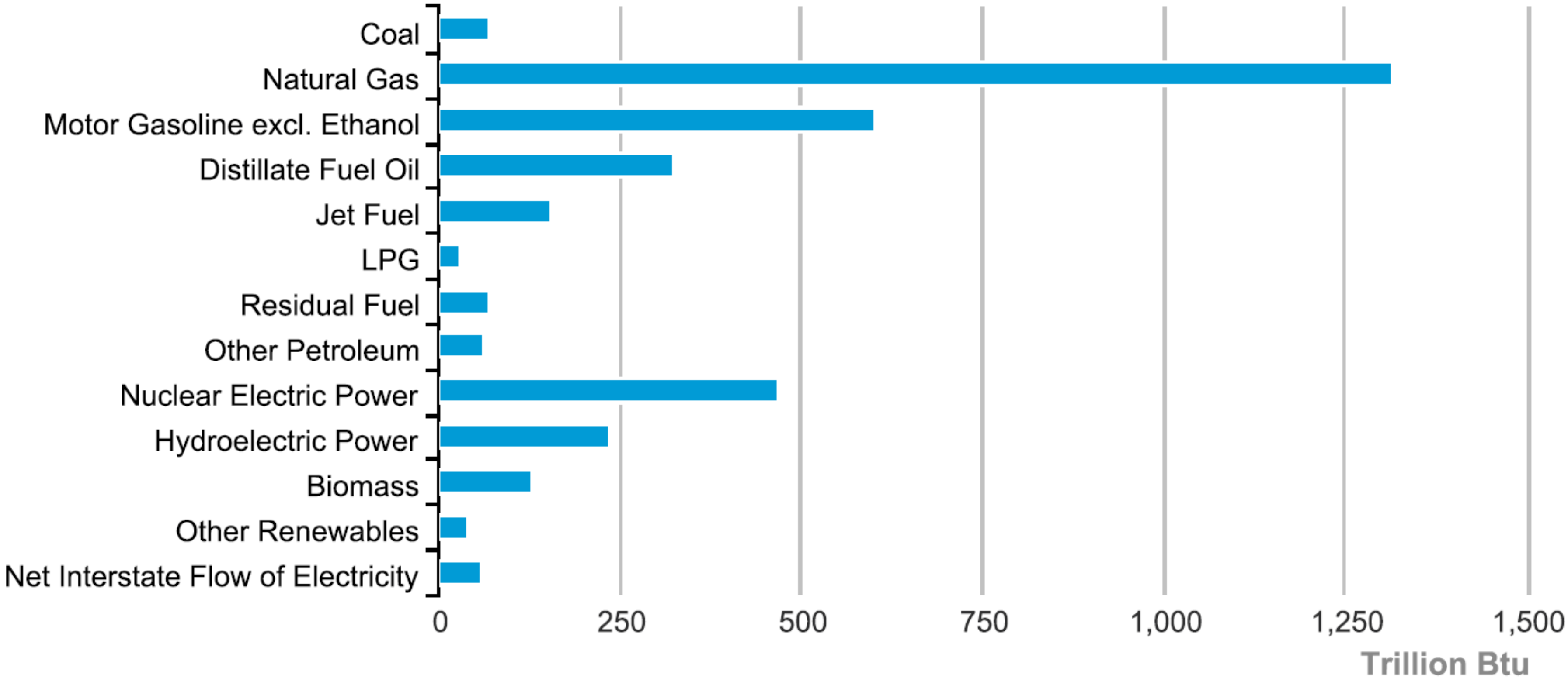
California Energy Consumption Estimates, 2013



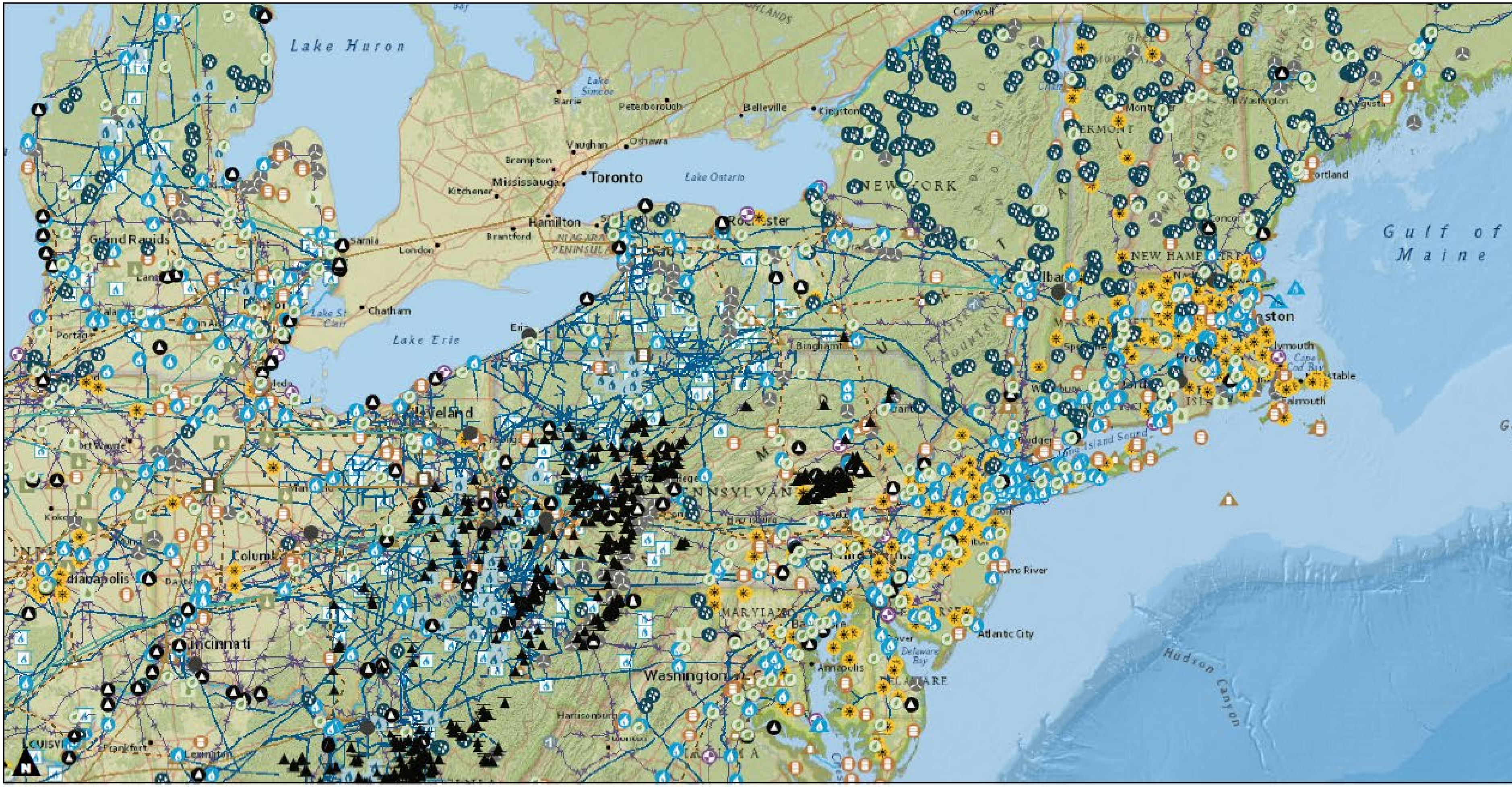
Source: Energy Information Administration, State Energy Data System


State Mask
Surface Coal Mine
Underground Coal Mine
Biomass Power Plant
Coal Power Plant
Geothermal Power Plant
Hydroelectric Power Plant
Natural Gas Power Plant
Nuclear Power Plant
Other Power Plant
Petroleum Power Plant
Pumped Storage Power Plant
Solar Power Plant
Wind Power Plant
Petroleum Refinery
Biodiesel Plant
Ethanol Plant
Natural Gas Processing Plant (z)
Ethylene Cracker
HGL Market Hub (z)
Natural Gas Market Hub (z)
Crude Oil Pipeline (z)
Petroleum Product Pipeline (z)
HGL Pipeline (z)
Natural Gas Inter/Intrastate Pipeline (
Electric Transmission Line (≥345kV) (
Crude Oil Rail Terminal
San Francisc
San Jos
Santa Ros
San Luis Obi
Santa Maria
Lompoc
Oxnar
Long Be
Oceanside
n Diego
Lake Havasu C
Davidson Seamount
Rodriguez Seamount
San Juan Seamount

New York Energy Consumption Estimates, 2013



Source: Energy Information Administration, State Energy Data System



layer0:Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA,

Surface Coal Mine	Nuclear Power Plant	Biodiesel Plant	Crude Oil Pipeline (z)	Petroleum Port
Underground Coal Mine	Other Power Plant	Ethanol Plant	Petroleum Product Pipeline (z)	Natural Gas Underground Storage (z)
Biomass Power Plant	Petroleum Power Plant	Natural Gas Processing Plant (z)	HGL Pipeline (z)	LNG Import/Export Terminal
Coal Power Plant	Pumped Storage Power Plant	Ethylene Cracker	Natural Gas Inter/Intrastate Pipeline (z)	Northeast Petroleum Reserve
Geothermal Power Plant	Solar Power Plant	HGL Market Hub (z)	Electric Transmission Line (≥345kV) (z)	Strategic Petroleum Reserve
Hydroelectric Power Plant	Wind Power Plant	Natural Gas Market Hub (z)	Crude Oil Rail Terminal	Waterway for Petroleum Movement
Natural Gas Power Plant	Petroleum Refinery		Petroleum Product Terminal	

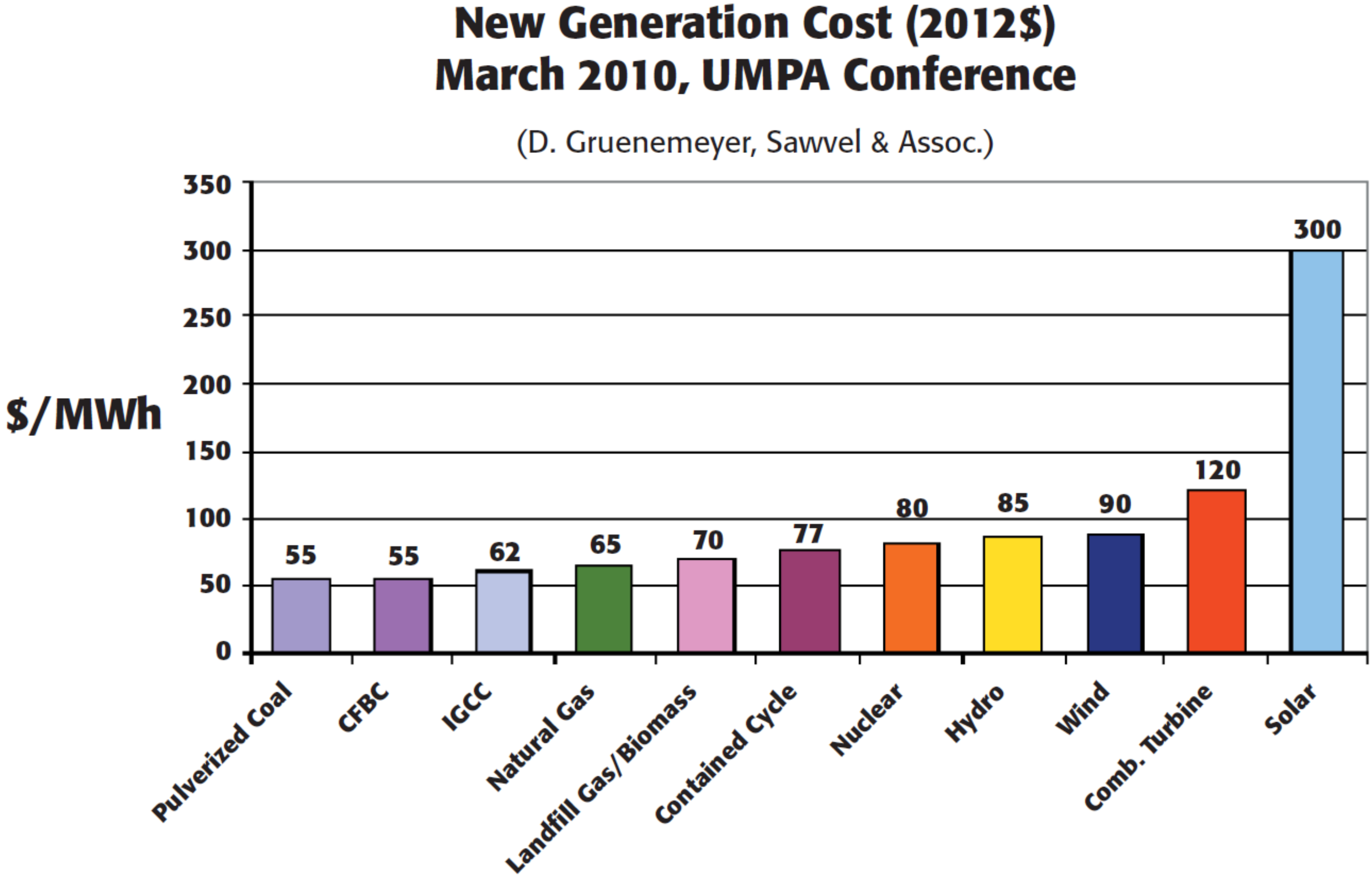
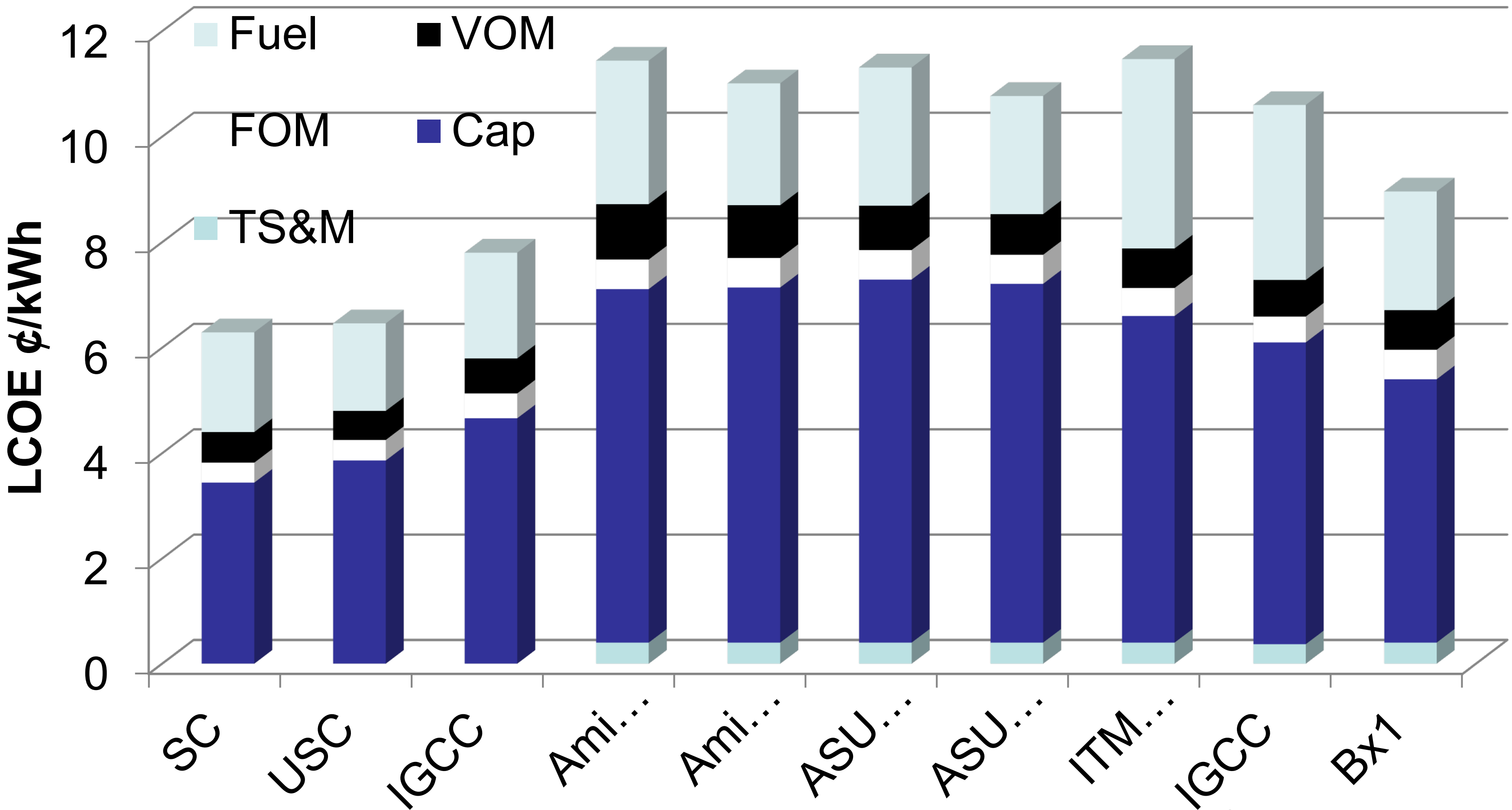


Figure 3. Estimated Costs of Energy Generation.
Source: D. Gruenemeyer, Sawvel and Associates.[35]

From "Energy Initiatives and Imperatives: Utah's 10-Year Strategic Energy Plan," Governor Gary R. Herbert (March 2, 2011)

Levelized Cost of Power
(with carbon capture and sequestration)



Uses data from DOE, 2007

Cases are supercritical (current, modern technology), ultrasupercritical (10 year out developing technology), integrated gasification combined cycle, and these technologies with amine-based absorption, cryogenic air-separation unit (ASU), ion transport membrane (ITM), and two new processes.
Categories are fuel, variable operating & maintenance, fixed operating & maintenance, capital, and transportation, storage & monitoring.