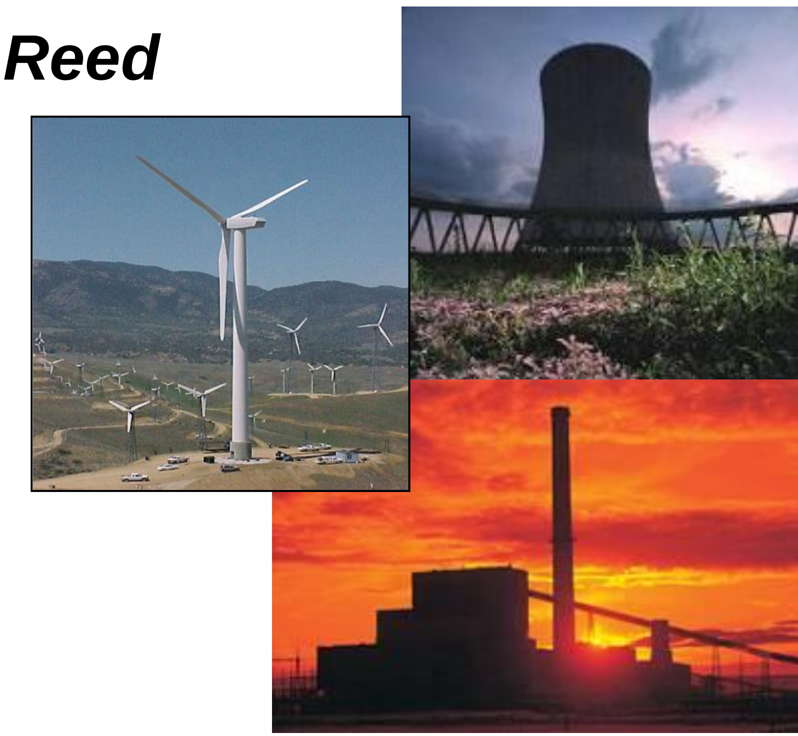
Innovative Management of Carbon Emissions from Fossil Plants

Joseph D. Smith, Ph.D. , Michael Reed

Advanced Process and Decision Systems

Idaho National Laboratory
Idaho Falls, ID

joseph.smith@inl.gov



24th Annual ACERC Conference

February 25-26, 2010 Provo, UT

Outline, Objectives, and Conclusions

- **Outline:**
  - Today's Grand Energy Challenge
  - Hybrid Energy Systems involving Fossil Energy
  - High Temperature Steam Electrolysis Applied to Fossil Energy Systems (HTSE)

- **Objectives:**
  - *Discuss Energy Security Issues related to Fossil Energy and Climate Change*
  - *Present "Next Generation" Hybrid Energy Concepts*
  - *Demonstrate Application of HTSE to Fossil Energy Systems*

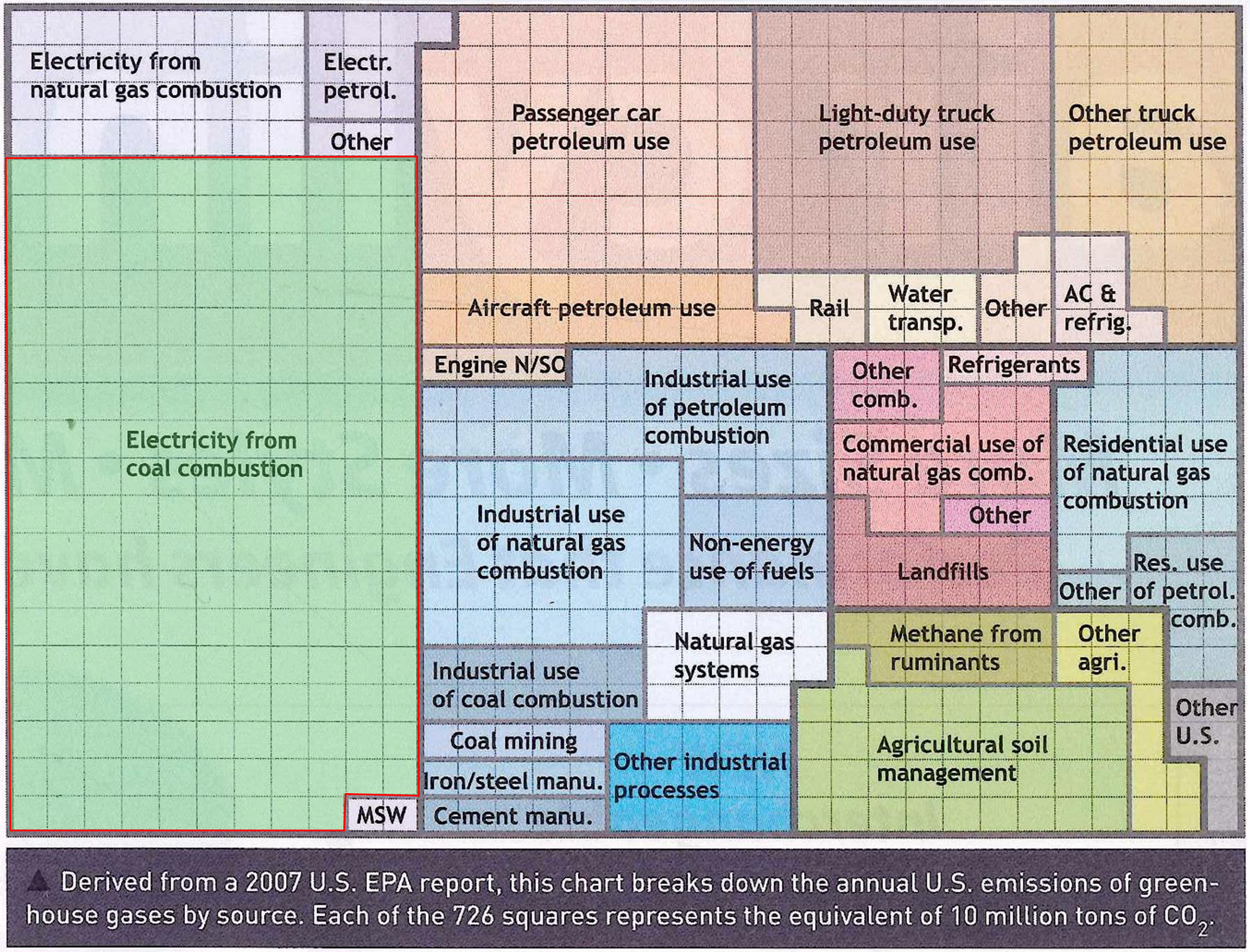
- **Conclusions and Recommendations:**
  - *Transformational Technology in HES coupled with Fossil Energy is of path to "Next Generation" Energy Systems that Preserve U.S. Energy Security and Manage Climate Change*
  - *Hybrid Energy Systems represents Integrated Path Forward to Provide Greener/Higher Value Jobs, Improved Energy Security, Energized Industrial Base, and Sustainable "Green" Prosperity*
  - *Collaboration Represents an Excellent Opportunity to Apply HES Technology in "Living Laboratory" required to bring technology to society*

Today's Grand Energy Challenge

DOE undergoing rapid & dramatic expansion with unprecedented influx of funds to execute "Energy Independence" mission

Federal Laboratories, including INL, are focused on developing "Transformational" Energy Technology to assist federal government in implementing a Clean, Secure, Efficient Energy Policy

Fossil Fuel CO2 Sources *(USEPA, 2007)*



Idaho National Laboratory

Higher Temp/Press + Fluid Bed Combustors

Pulverized coal option	Steam Conditions	Typical Efficiency (% HHV)
Subcritical	<22.1 MPa/538°C/538°C	35.0-38.0
Supercritical (SC)	24.7 MPa/538-565°C/565°C	38.0-40.0
Ultra-supercritical (USC)	27 MPa/565-625°C	40.0-42.5
Advanced USC	27 MPa/above 625°C	42.5-46.0

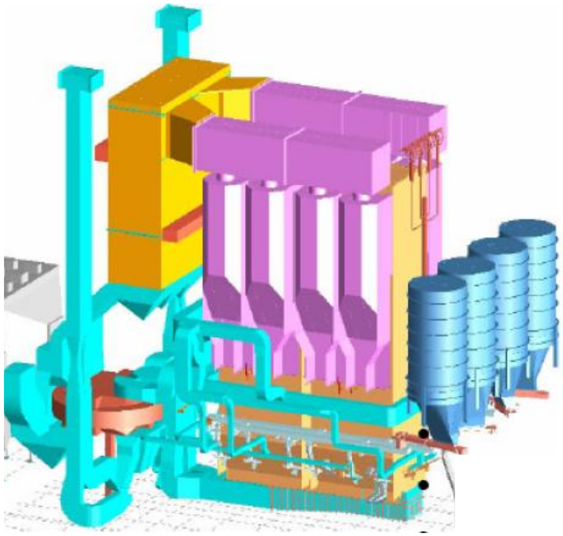
Conclusion: Higher Pressure/Temperature = > Higher Efficiency!

Tavoulareas, S., "Supercritical Technology – An Overview," *Cleaner Coal Workshop on Solutions to Asia's Growing Energy and Environmental Challenges*, Halong City, 19-21 Aug (2008)

Low Quality Fuel is a Significant Challenge!

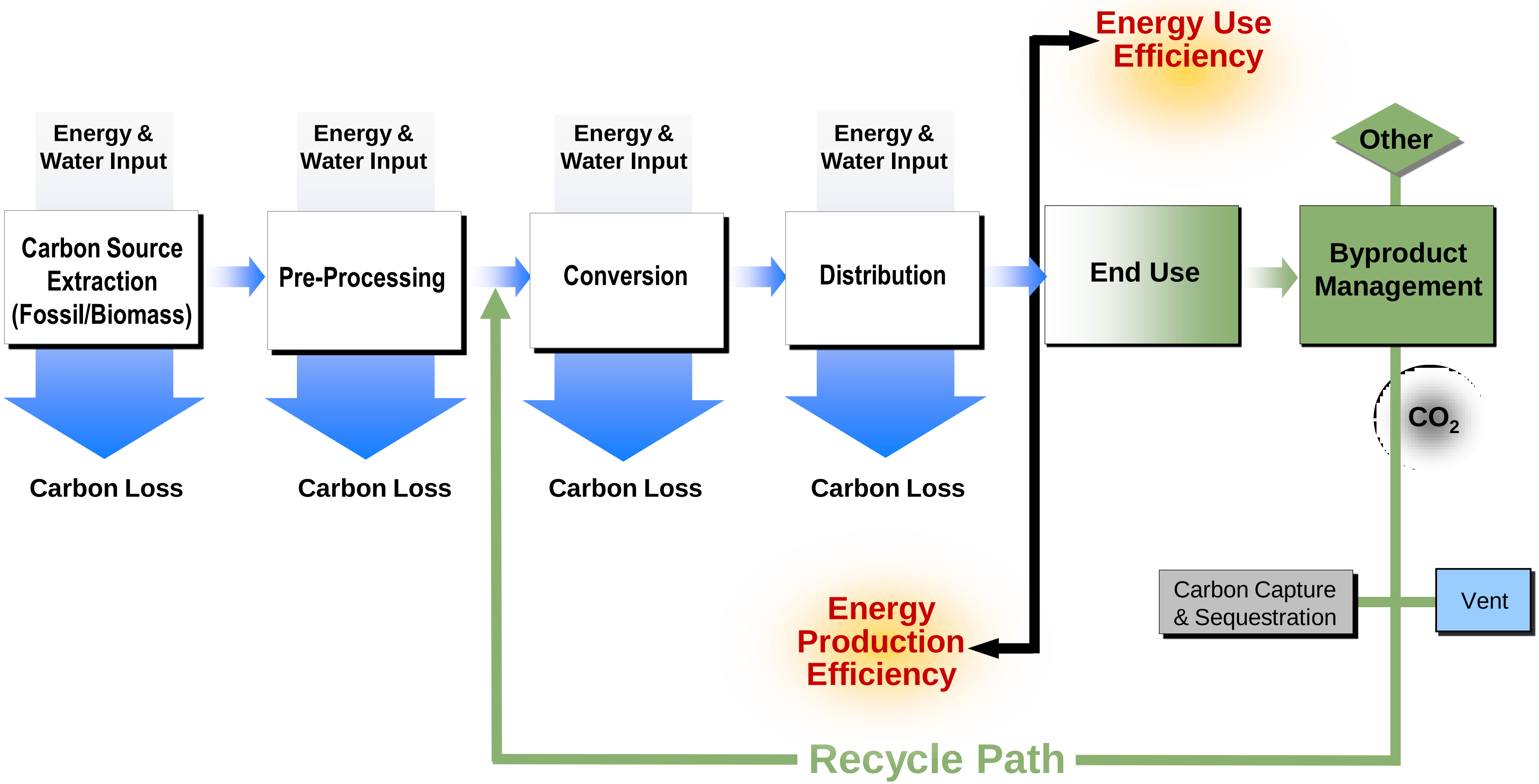
- Lignite-fired pulverized power plants
  - Worldwide capacity (operating and planned): 54.4 GWs
    - China: 43 GWs (low volatile and lignite)
    - Spain: 3.0 GWs (incl. 7 x 300 MW)
    - United Kingdom: 1.9 GWs (incl. 3 x 500 MW)
    - Vietnam: ~1.9 GWs
    - Germany: 1.1 GW (largest plant – 750 MW)
  - Nearly all plants have the same design
  - Low volatile Lignite difficult to burn
  - "Downshot firing" produces "W-Flame"

From W-fired boiler



To Circulating Fluid Bed

"Full" Lifecycle Management (Carbon + Water)



Idaho National Laboratory

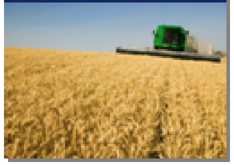
INL's Advanced Hybrid Energy Research Focus

Clean Energy Systems

Regional Energy Technology Leadership

Total Carbon Management Approach

Integrated Energy Systems

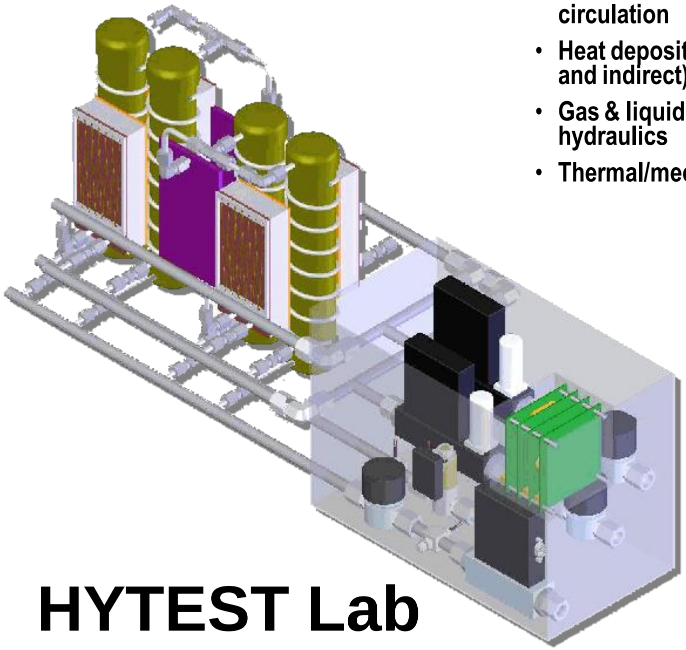
Bioenergy Technology	Renewable Energy Technology	Unconventional Resource Recovery & Process Technology	Advanced Energy Systems and Surety	Advanced Vehicles & Batteries	Energy Efficiency & Industrial Competitiveness
					

Idaho National Laboratory

INL HYTEST Process Platforms

Feedstock Processing

- Resource extraction: fossil fuels and biomass
- Feedstock assembly
- Thermal treatment: pyrolysis, gasification, steam reforming, etc.

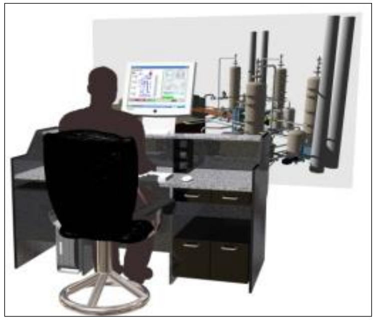


HYTEST Lab

Energy Integration

- Heat exchanger/ heat circulation
- Heat deposition (direct and indirect)
- Gas & liquids thermal hydraulics
- Thermal/mechanical

System Integration, Monitoring & Control



- Reliability, availability, maintainability, and surety optimization
- Signal processing and parameter estimation
- Advanced process diagnostics and supervisory control systems
- Process modeling & visualization

Byproduct Management

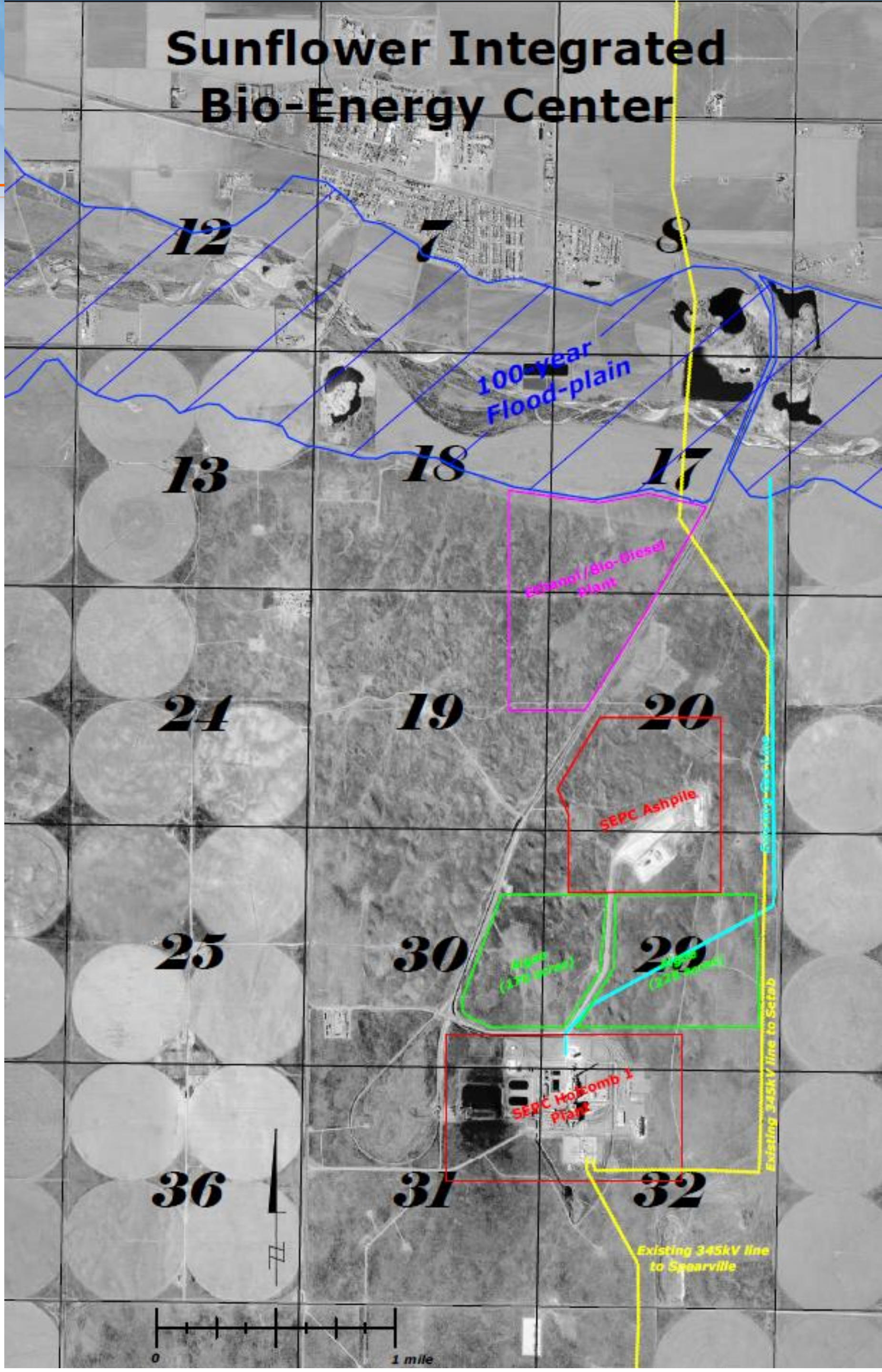
- CO_2 separation and recycle or sequestration
- Alternative CO_2 uses: EOR, solids slurries, reduction to fuel
- Enhanced algae photosynthesis

Energy Storage

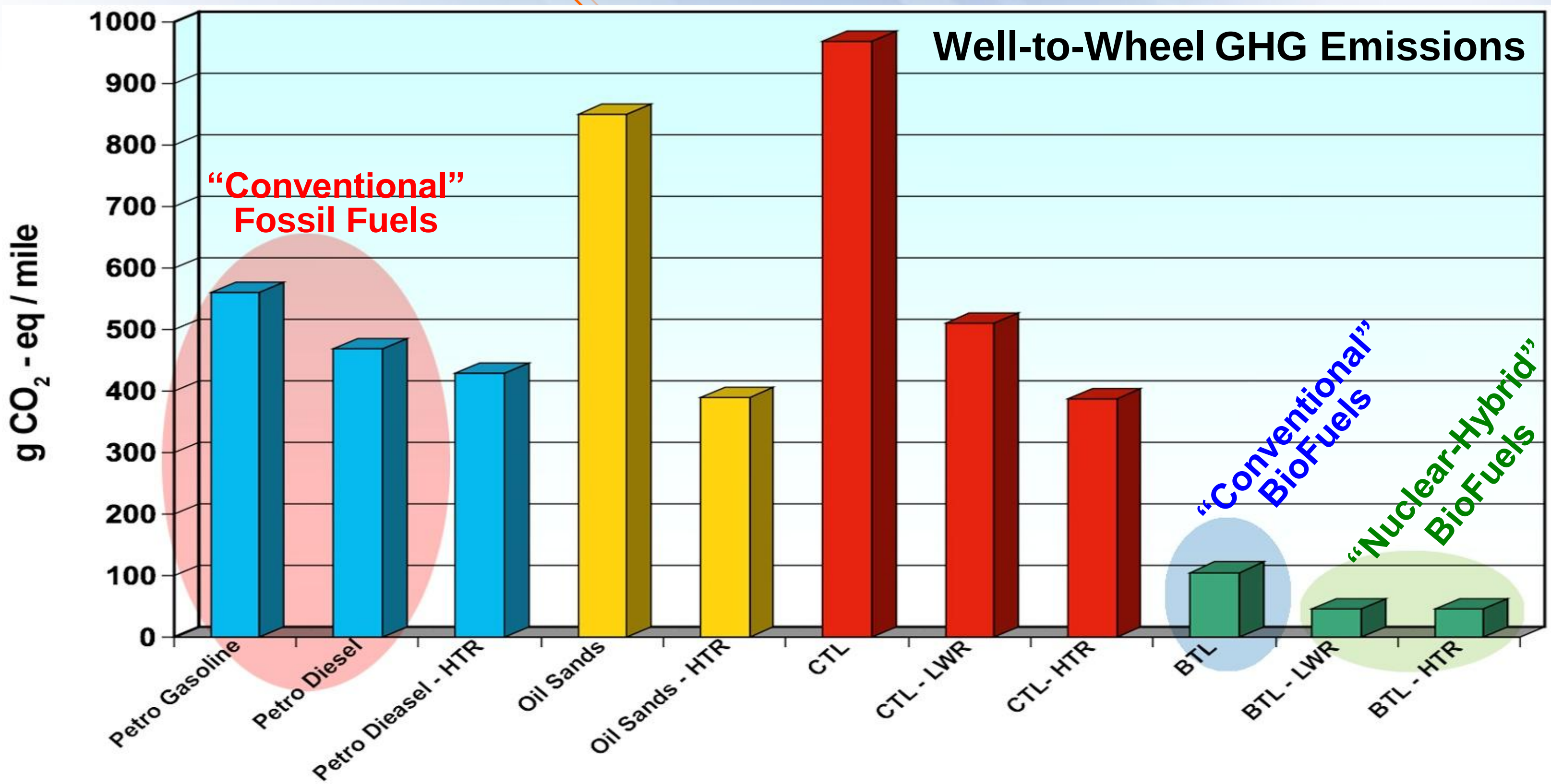
- Hydrogen generation HTSE and chemical loops
- Catalysis: F-T fuels, SNG, alcohols, ammonia, etc.
- Electrical: Batteries, capacitors, etc.

"Hybrid Energy Systems"

- Combine multiple energy sources
- Single site (plant) or regional
- Efficient/cleaner production of electricity, liquid fuels, and chemicals
- Support Micro-grids
- Examples considered:
  - Wind + coal
  - Solar + Biomass
  - Nuclear + coal
  - Nuclear + oil shale
  - Nuclear + wind + coal



Lifecycle Emissions of Liquid Fuels



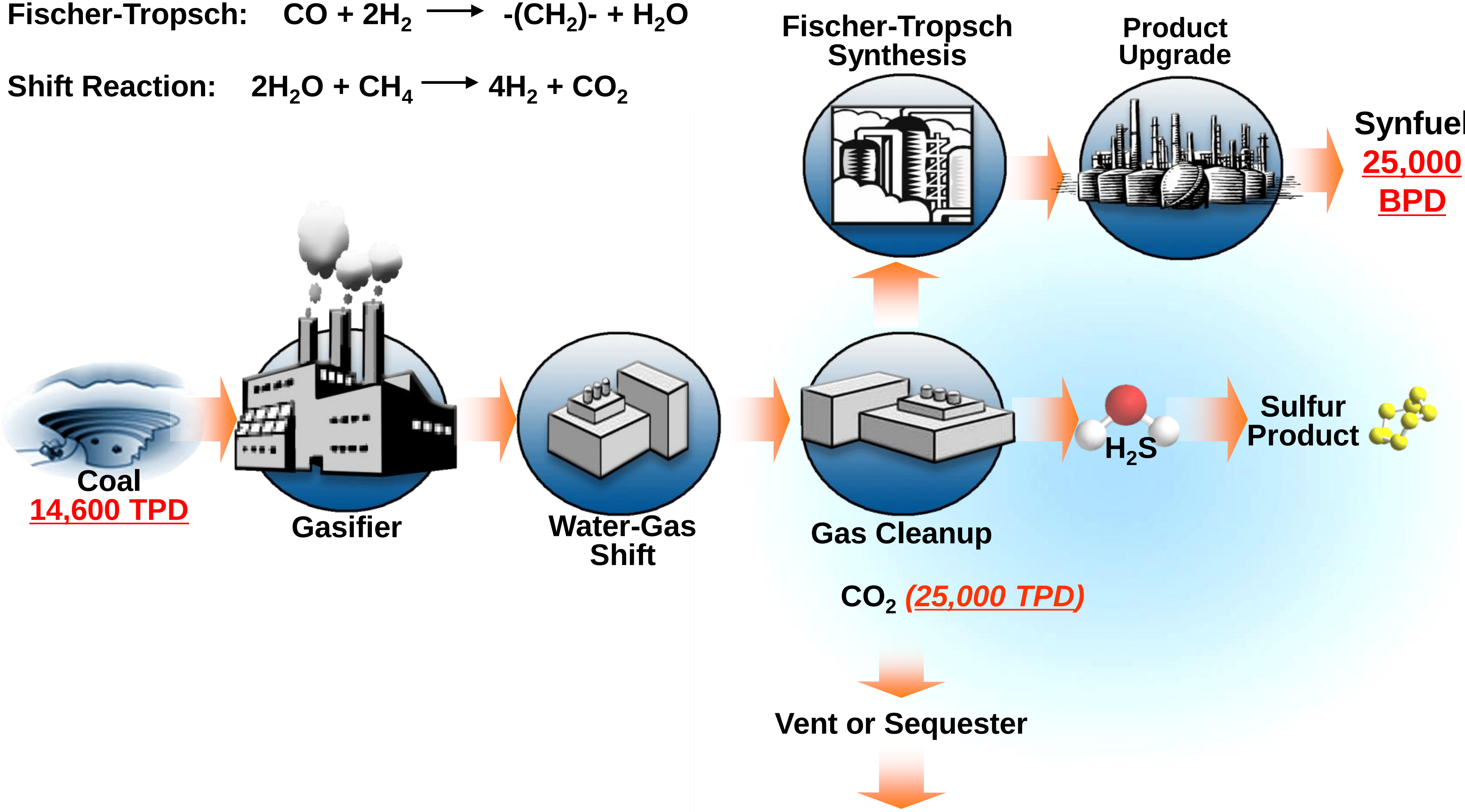
- Fischer-Tropsch: $CO + 2H_2 \longrightarrow -(CH_2)- + H_2O$
- Shift Reaction: $2H_2O + CH_4 \longrightarrow 4H_2 + CO_2$
- Nuclear energy decreases the carbon cost of all systems to levels well below the current baseline
- Best results are with a nuclear-biomass hybrid

Idaho National Laboratory

Fossil-Fuel Coal to Liquid: Current Approach

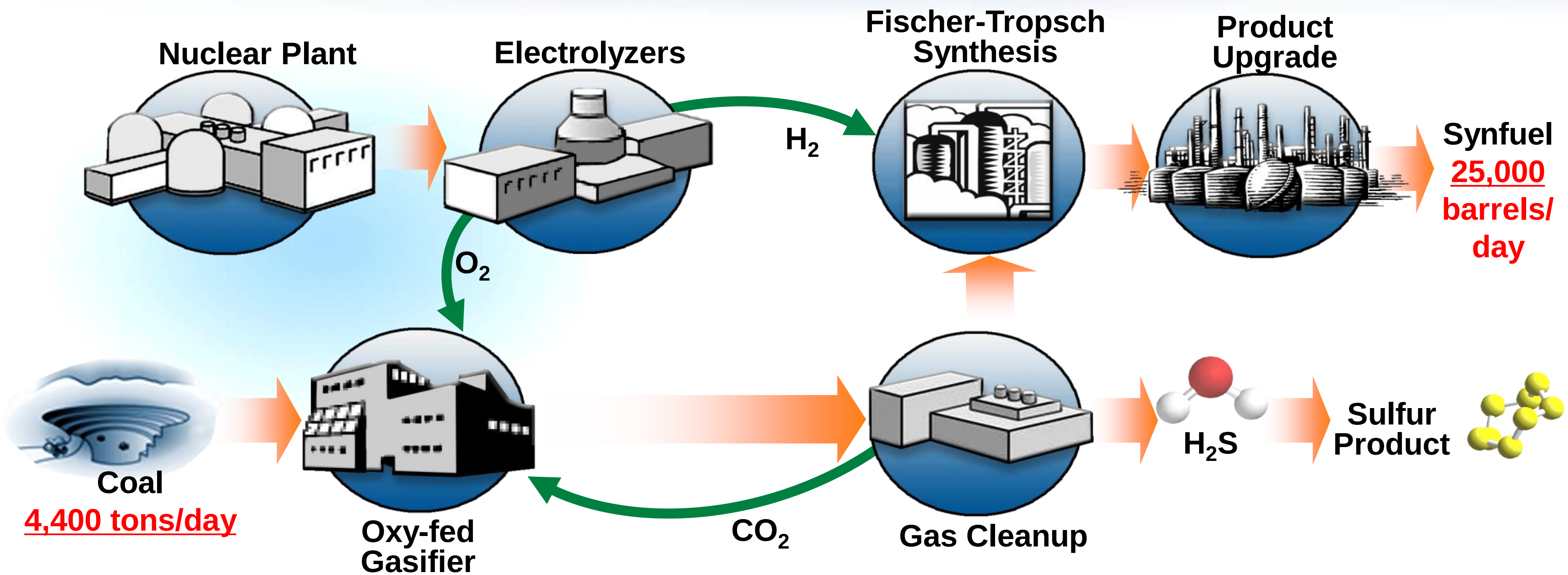
Fischer-Tropsch: $CO + 2H_2 \longrightarrow -(CH_2)- + H_2O$

Shift Reaction: $2H_2O + CH_4 \longrightarrow 4H_2 + CO_2$



Idaho National Laboratory

Next Generation Hybrid System: Nuclear/Coal to Liquid

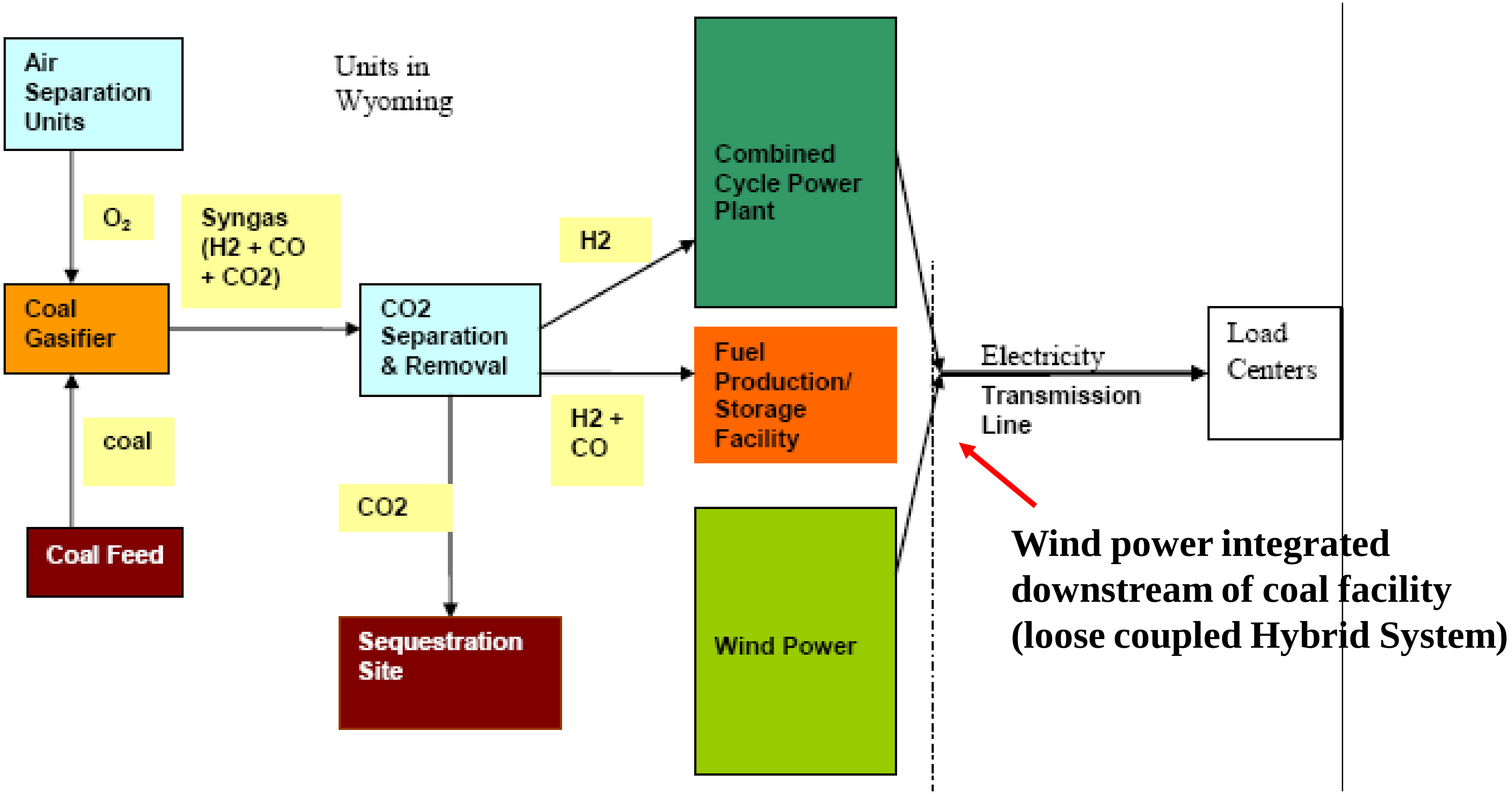


- Hybrid systems use 70% less coal
- Little carbon converted to CO_2
- Small amount of CO_2 recycled to gasifier
- Effectively <u>NO</u> CO_2 emissions
- Can use renewable energy sources (i.e., wind, solar, hydro, geo-thermal, etc.):
  - Intermittency issues require operating flexibility or storage (i.e., as liquid fuels)
  - Can be smaller scale than dedicated nuclear plant

Idaho National Laboratory

Present Concept: Reduce CO2 via Integrated Fossil/Wind Hybrid

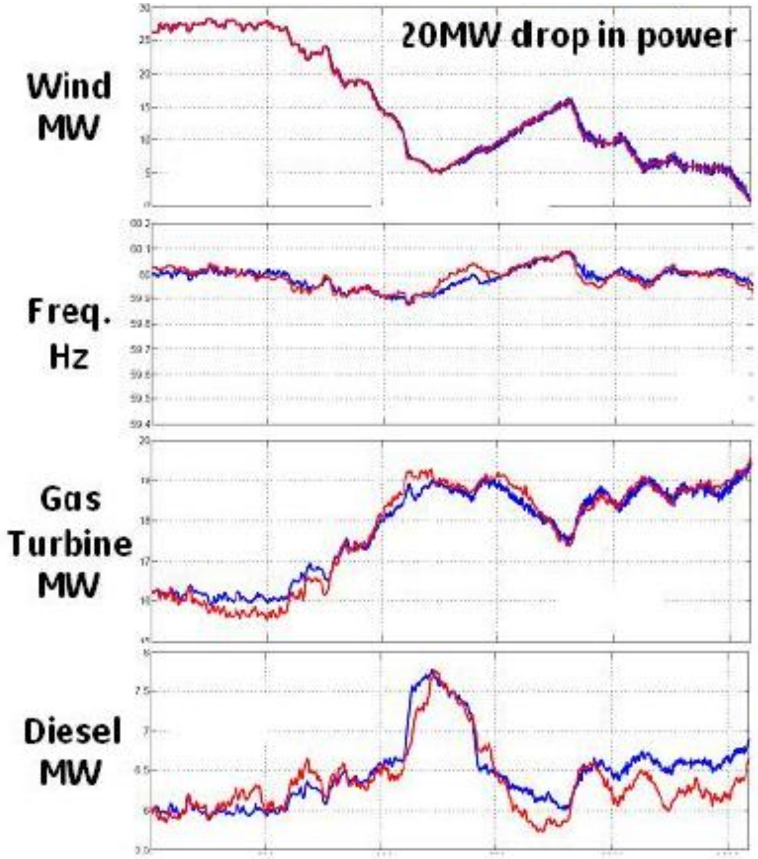
- **Screening level analysis of wind farms + advanced coal fired power plant (Western U.S.)**
- **Electric Power Production with Bio-Fuels is Preferred option**
  - **Lower levelized electricity cost**
  - **Reduced carbon footprint**
  - **Competitive with other generation technologies**



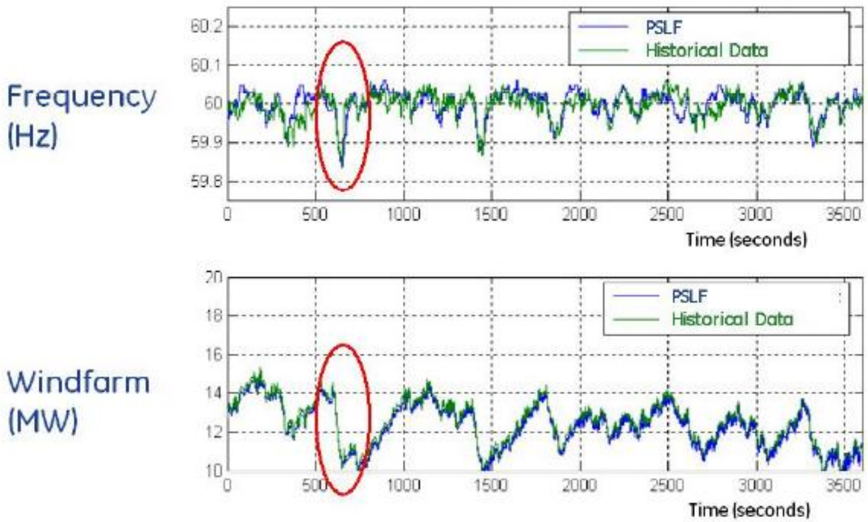
Source: Lawrence Berkeley National Laboratory Report 1248E: Advanced Coal Wind Hybrid: Economic Analysis, December 2008

Idaho National Laboratory

Example: Fossil/Wind Dynamics!



GE PSLF™ AGC Model
Wind event from Feb 11, 2008



Sudden, fast fluctuations in wind power inbalances the load and generation => system frequency deviates

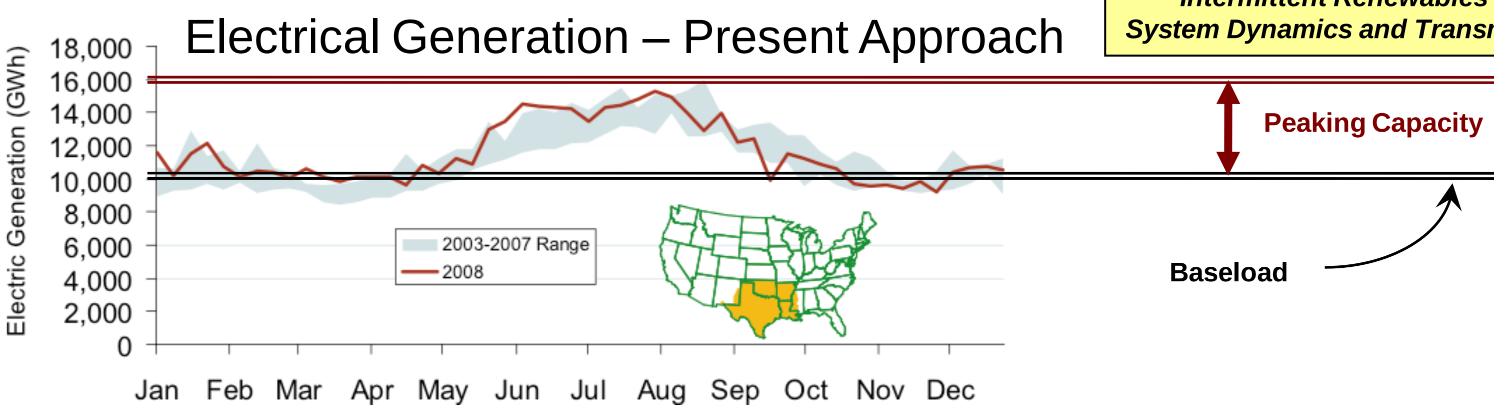
Gas units ramp up to address imbalance => efficiency penalty

Integrated Hybrid Systems designed to provide rapid response to imbalance

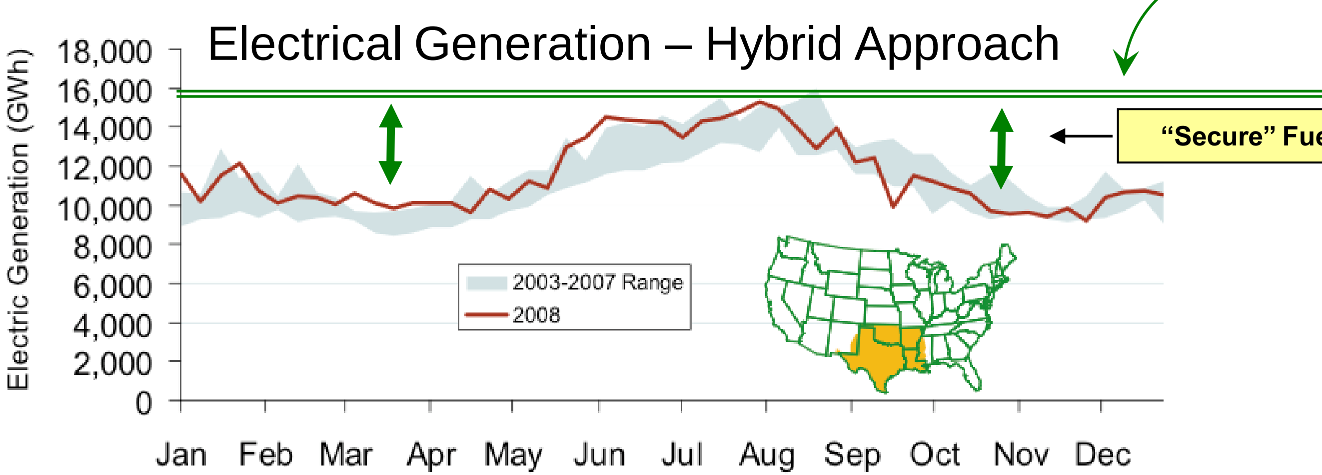
Idaho National Laboratory

Energy Storage – Modified Base Load Generation

Intermittent Renewables Constrained By System Dynamics and Transmission Architecture



Operate at Baseload and convert excess energy into liquid fuels

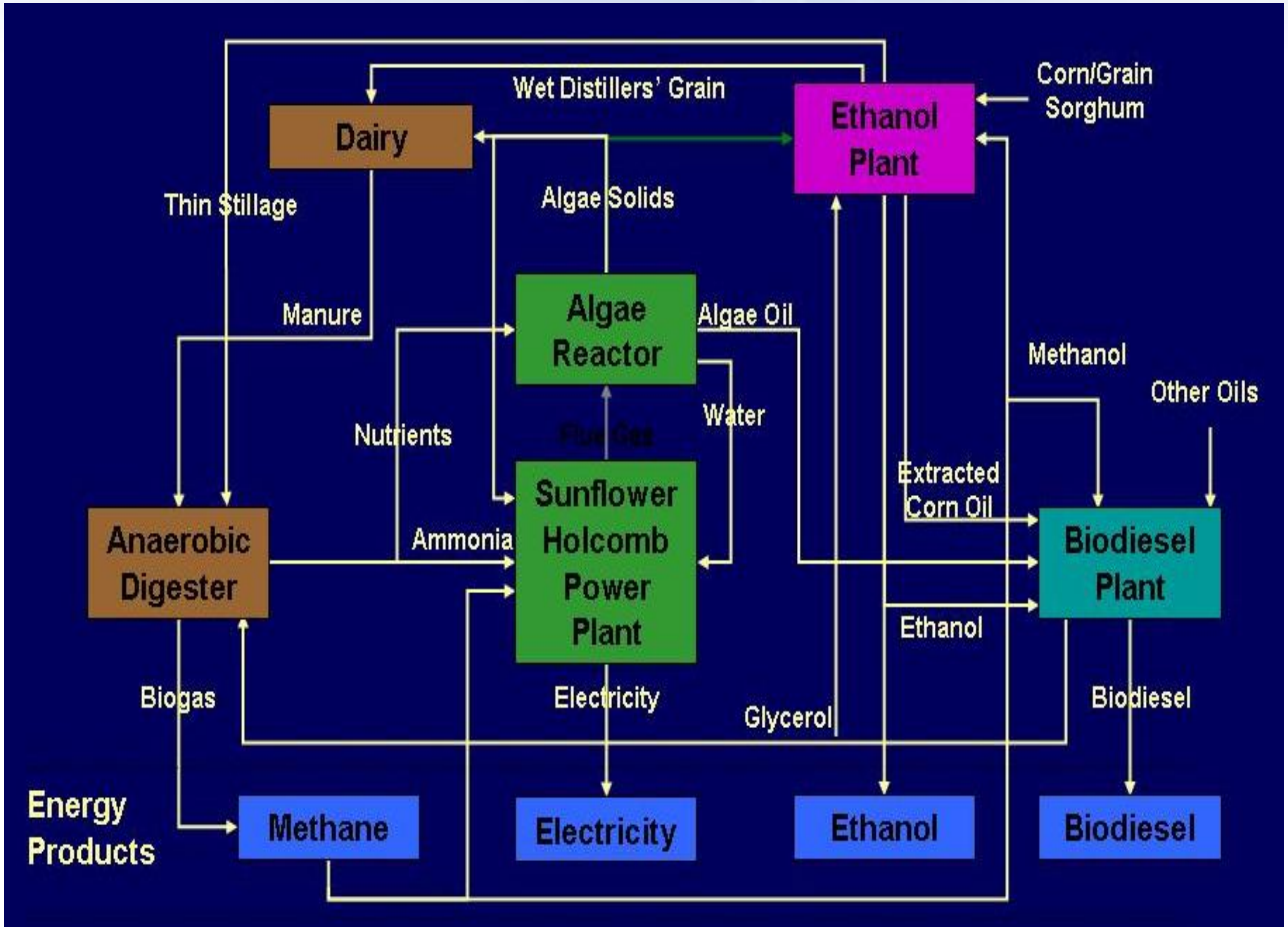


"Secure" Fuel Production = Energy Storage

Source: Market Oversight @FERC.gov

Idaho National Laboratory

Fossil + Renewable Example: Sunflower Bioenergy Center

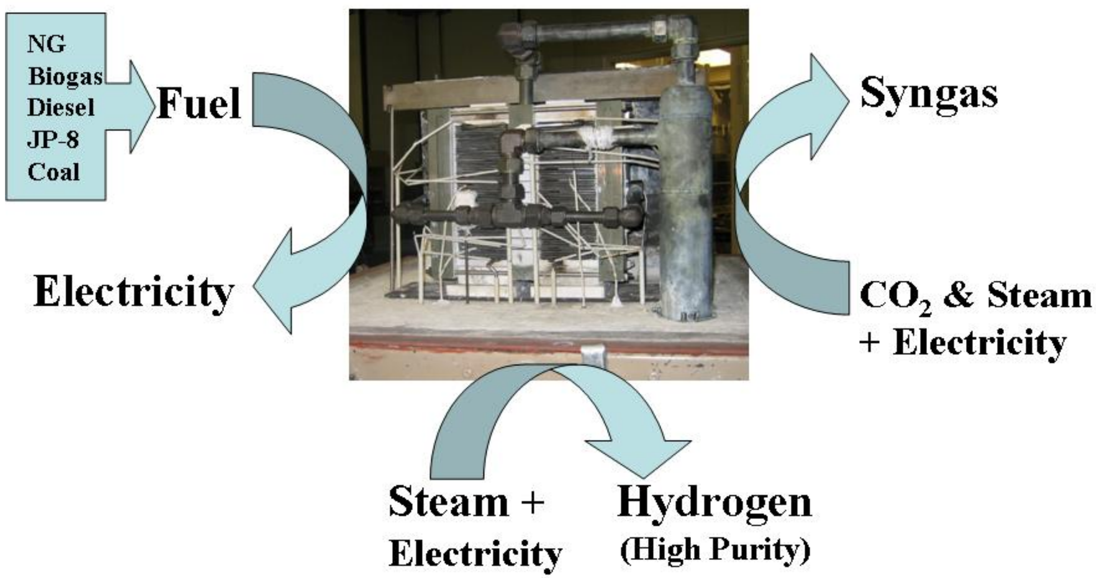


Hybrid Energy Systems support creation of Local and Regional Energy Clusters

Energy Storage – Key to Integrating Renewables and Managing CO2

- High Temperature Steam Electrolysis (HTSE) Generates "Green" H2, O2, CO
  - Efficient Operations @ Temperatures > 600 C
  - Power to Operate from Nuclear/Renewable Energy Sources
- HTE Minimizes Carbon Emissions:
  - Manages carbon emissions through conversion to liquid fuels
  - Starting point for commercial synthetic chemical products

Solid Oxide Stack Module



Operation:

- HT Steam & CO2
- Recycled CO2 from combustion process
- O2 produced at Electrode 1
- H2 & CO (Syngas) produced at Electrode 2
- O2/H2 feed to Process

Overview of HTE Test System

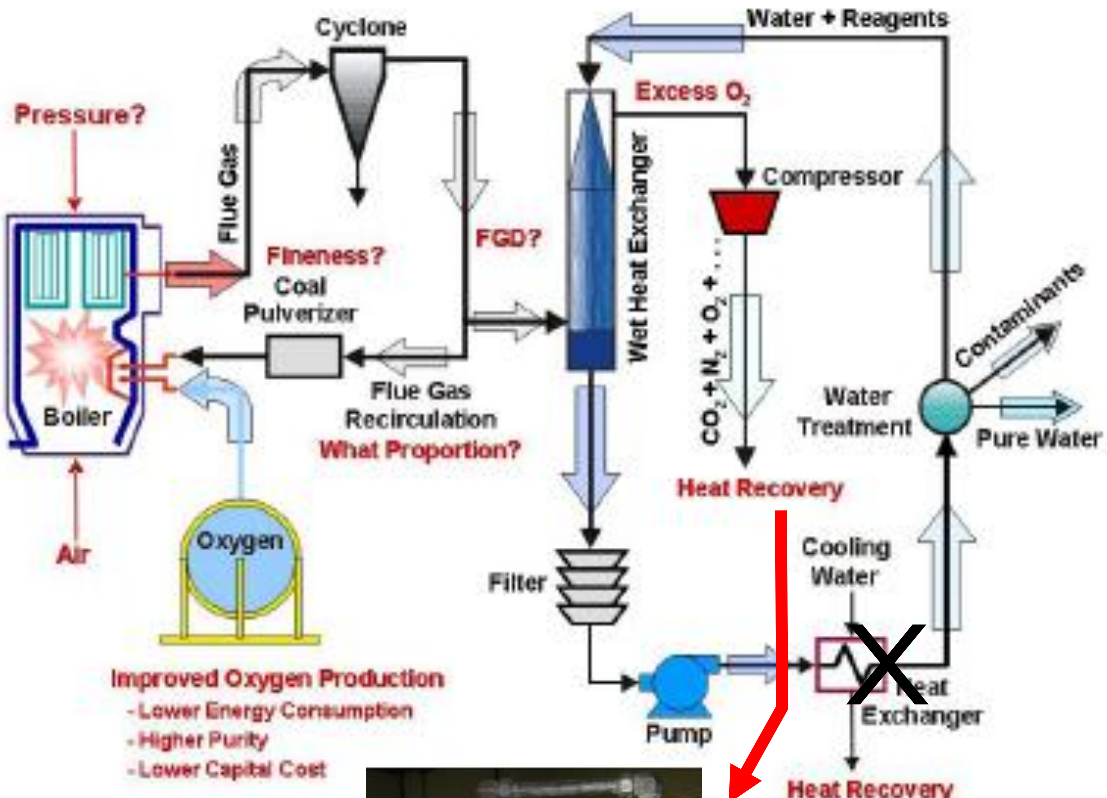
Pilot Scale Skid Unit Operated for 2500 hr test

Materials Degradation focus of long term Testing

Oxy-Combustion Combined with HTSE

Farzan, H., Vecci, S., McDonald, D., McCauley, K, Pranda, P., Varagani, R., Gautier, F., Tranier, J.P. and Perrin, N., "State of the Art of Oxy-Coal Combustion Technology for CO2 Control from Coal-Fired Boilers," *Third International Technical Conference on Clean Coal Technologies for Our Future*, Sardinia, Italy, May 15 - 17 (2007)

Carbon Sequestration: Oxy-Fuel Combustion, R&D Facts, NETL, www.netl.doe.gov

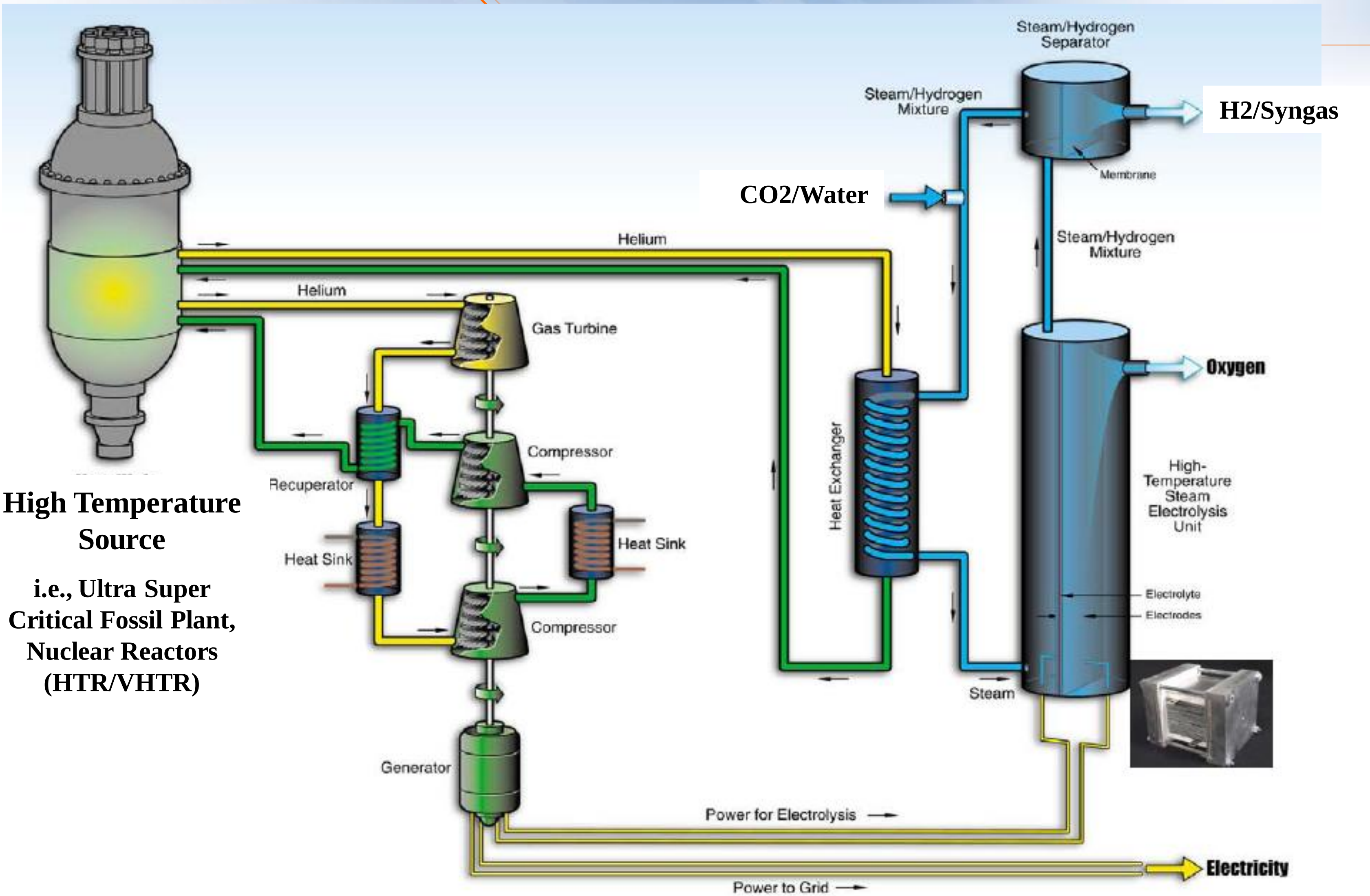


O2 fed from HTSE Unit

CO2/steam from Coal Plant fed to HTSE Unit

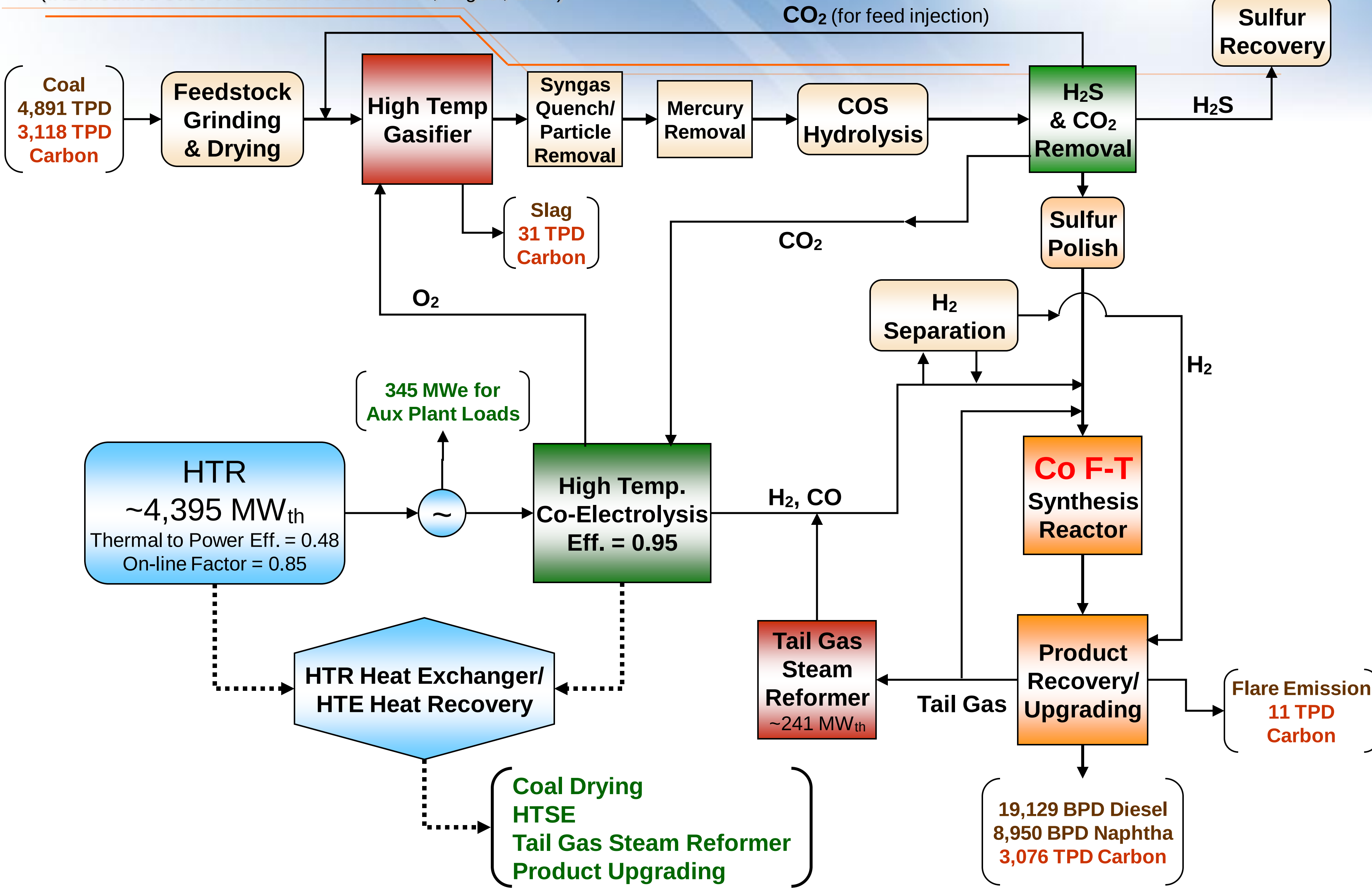
Idaho National Laboratory

High Temperature Steam “Co-Electrolysis” Plant



Design Example: CTL / High Temperature Reactor Hybrid

(INL Modified Case of DOE/NETL-2007/1298, August, 2007)



Nuclear/CTL Hybrid System Details

Key Features

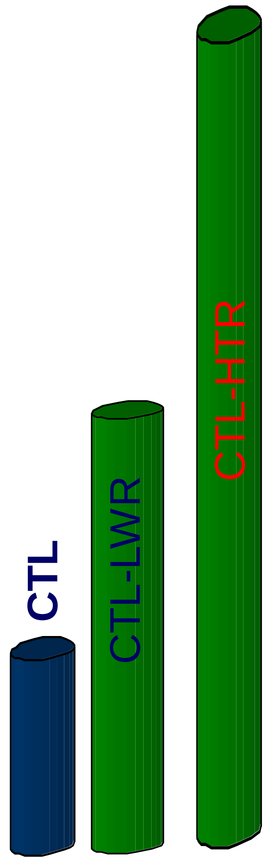
- **Electric power plus steam for High Temp Co-electrolysis (HTCE)**
- **HTCE recycles CO2 from coal gasifier**
- **H2 for F-T Fuel synthesis and hydrotreatment/ hydrocracking**
- **Maximize carbon to liquid products w/ HT tail gas reforming**
- **Replace ASU for O2**
- **Replace Shift reactor for H2**
- **Total power requirements provided by HTR**
- **Eliminates tail gas boiler**
- **Eliminates process heaters for fuel upgrading/refining**

LWR Benefits

- 93% more F-T liquid fuel for same carbon input
- 60% less CO2 emissions than "standard" CTL

HTR Benefits

- 266% more F-T liquid fuel for same carbon input!
- 99% less CO_2 emissions than "standard" CTL!



Fuel Production

Idaho National Laboratory

Conclusions

- Transformational Technology in HES coupled with Fossil Energy is of path to "Next Generation" Energy Systems that Preserve U.S. Energy Security and Manage Climate Change
- HES Utilizes Multiple Carbon Sources to Expand "Domestic" Energy Resources
- Using HES, Operate Energy Plants at Base Load Capacity (more efficient) and capture renewable energy via energy storage by converting to liquid fuels
- HES provides 70% Reduction in Carbon Emissions from traditional CTL Process
- High Temperature Steam (Co-) Electrolysis Helps manage CO2 emissions and provides H2 for upgrading renewable energy sources (biomass)
- INL "HYTEST" Laboratory focused on evaluating and demonstrating Hybrid Energy Systems Concepts
- HES capable of creating regional "energy clusters" that create new industry and associated jobs plus improves national energy security
- INL/CRN Collaboration Provides Excellent Opportunity to Apply HES Technology in "Living Laboratory" required to bring technology to society