Status and Value Proposition of Energy Storage Technologies

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Introduction

The presentation today will give an overview of the Carbon Capture Utilization Technologies for Capturing CO2 and economically using the CO2 enhanced oil recovery, conversion to liquid fuels, biofertilizers, etc.

Possible CO2 Removal Options

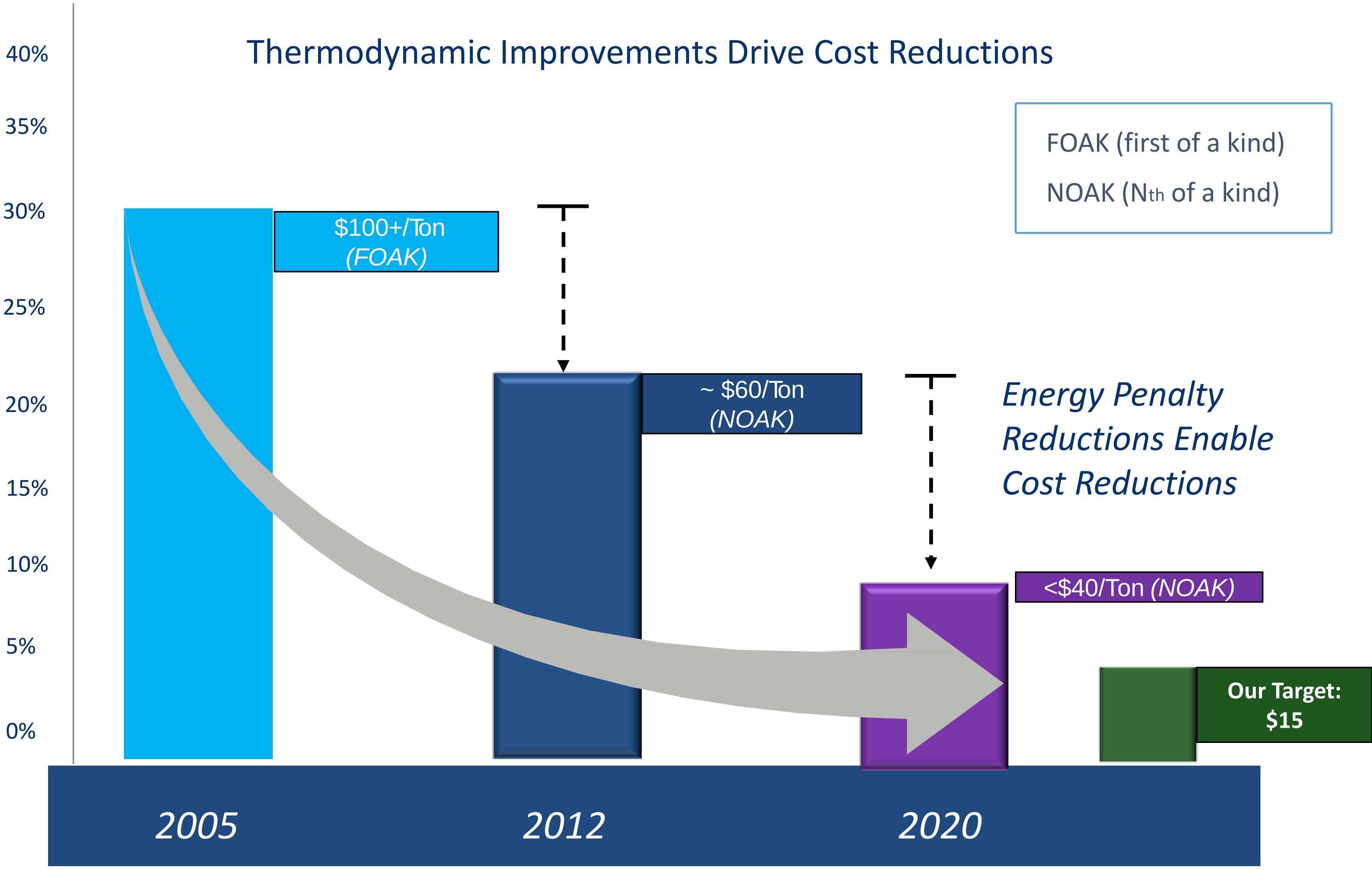
- Evaluation of options for carbon capture for natural gas is just beginning !
- Only 2 have tested at a pilot scale < 1 mWe Cansol , Carbon Clean Solutions India(CCSI)
- Linde/BASF Blue OASE - Coal
- Fuel Cell Technology – Coal
- MTR – Coal and some gas testing
- Air Liquide - Coal
- Research Triangle Institute (RTI) – testing Coal
- Sustainable Energy Solution Cryogenic Carbon Capture - Coal
- ION advanced amine based solvent – TCM testing on coal in Mongstad
- Inventys Veloxo Therm™ Post Combustion Capture - Coal
- Enviroambient LLC Post Combustion Capture - Coal
- GE amino silicone solvent - Coal
- Algae, Air /Soil applications - Coal
- OSU, NETL, others - Coal

DOE Carbon Program Goals

- **By 2020** - 90% capture at \$40/ton CO_2 captured (20% reduction in COE) – *2nd Generation Post*
- **By 2025** - 90% capture and <<\$40/ton CO_2 captured (30% reduction in COE) – *Transformational Pre & Post*
- **By 2020** – 75% capture using 2nd Generation technology optimized for NGCC – *Natural Gas*
- CO_2 Reuse technologies which can mitigate emissions at less than \$10/ton

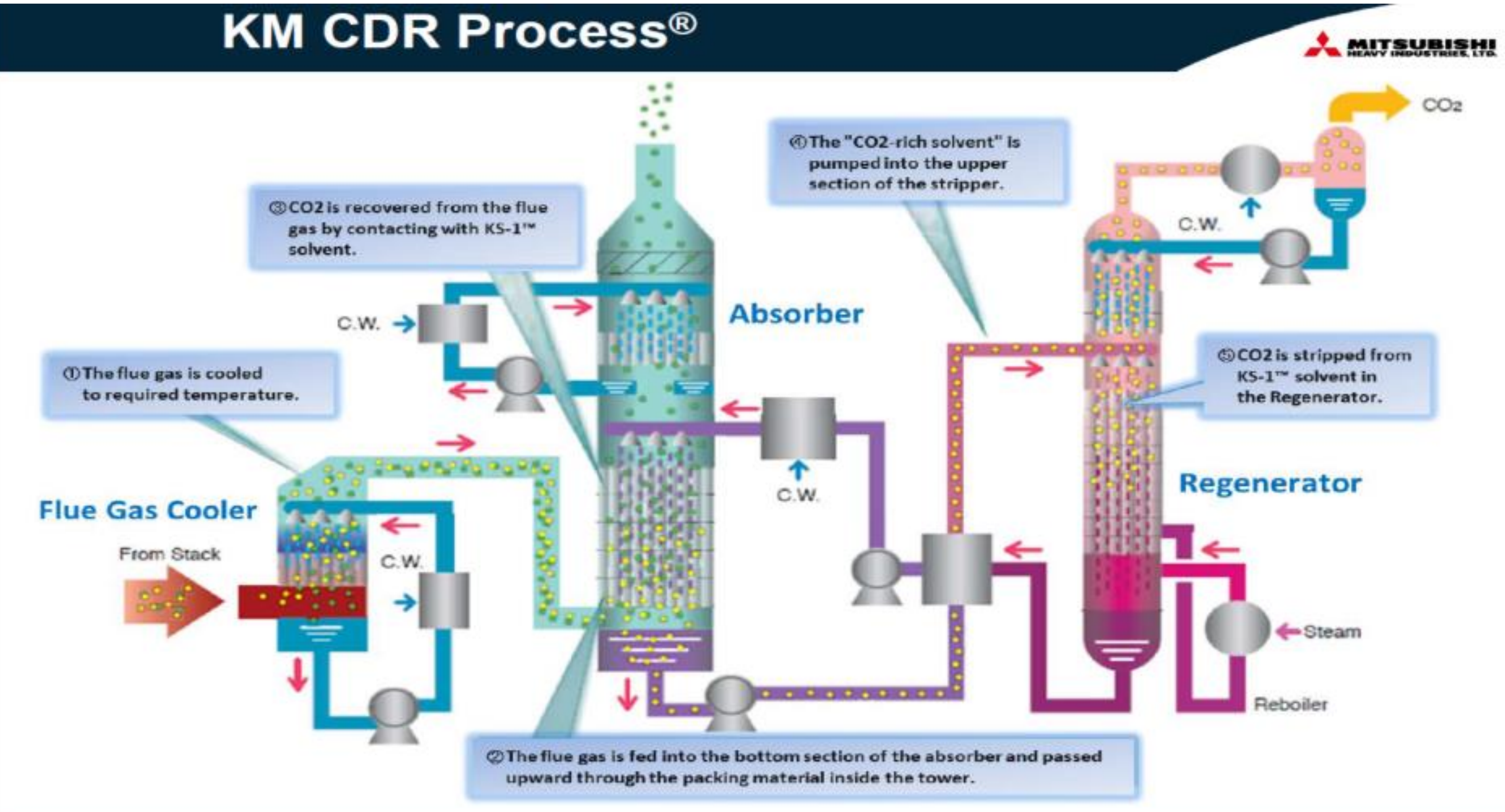
U.S. DEPARTMENT OF ENERGY

Clean Coal R&D



Source: DOE/NETL

MHI KM CDR process

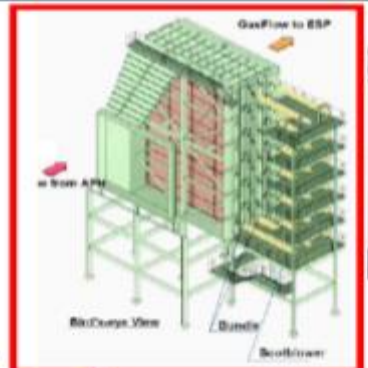


MHI KM CDR process with Flue Gas Waste Heat Recovery for a High Efficiency System (HES)

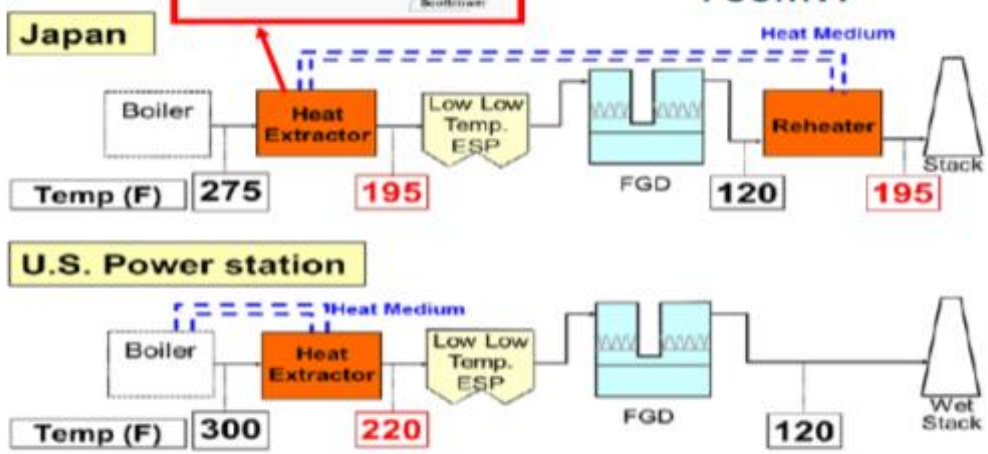
High Efficiency System (HES)

MITSUBISHI HEAVY INDUSTRIES, LTD.

- Commercially proven technology
  - Installed & operated at ten coal-fired units in Japan since 1997
  - MHPS's proprietary heat exchanger
- Benefits of HES
  - Removal improvement of hazardous air toxics (PM, SO_3, Hg, Se, etc.) across the ESP
  - Reduction of makeup & cooling water
  - AQCS (ESP, FGD & CCS) cost reduction
  - Reduction of total energy penalty of CCS plant
  - Potential to simplify boiler/steam turbine cycles



Tomato P/S Japan - 700MW



Commercial application of HES

MHI KM CDR process with MHPS proprietary Heat Exchanger

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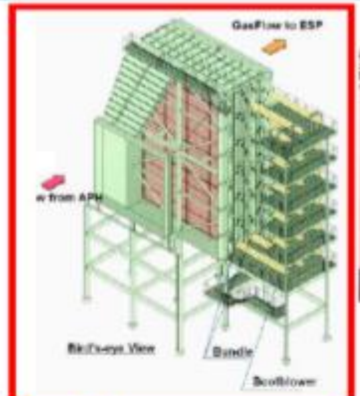
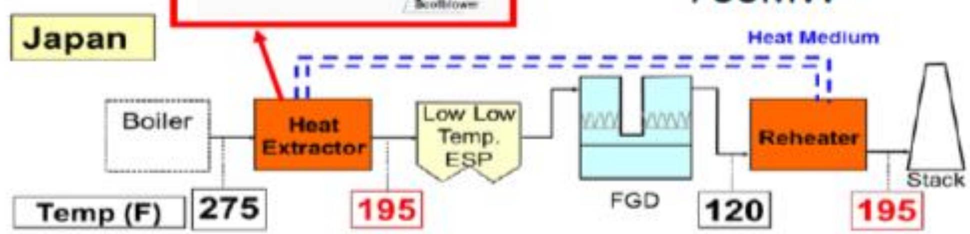
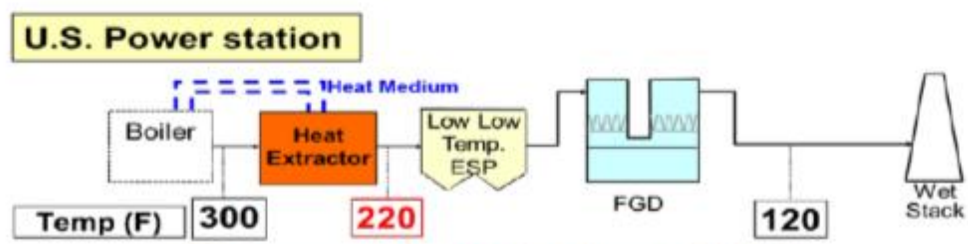


Tomato P/S Japan - 700MW





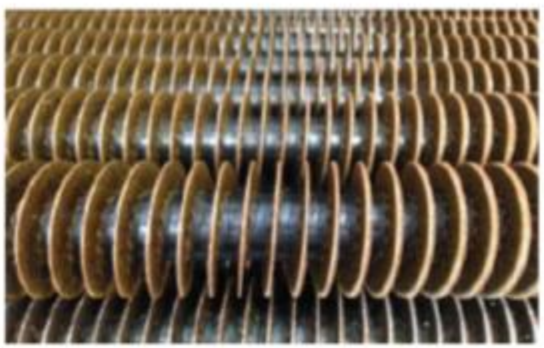
Commercial application of HES

MHI Proprietary Heat Exchanger

Durability Test Results (Preliminary)

MITSUBISHI HEAVY INDUSTRIES, LTD.

- Confirmed no significant corrosion on tube bundles
  - 4 wks w/o SO_3 injection, 3 wks w/ SO_3 injection
  - Detailed analysis is in progress



(a) Before operation

(b) October, 2015

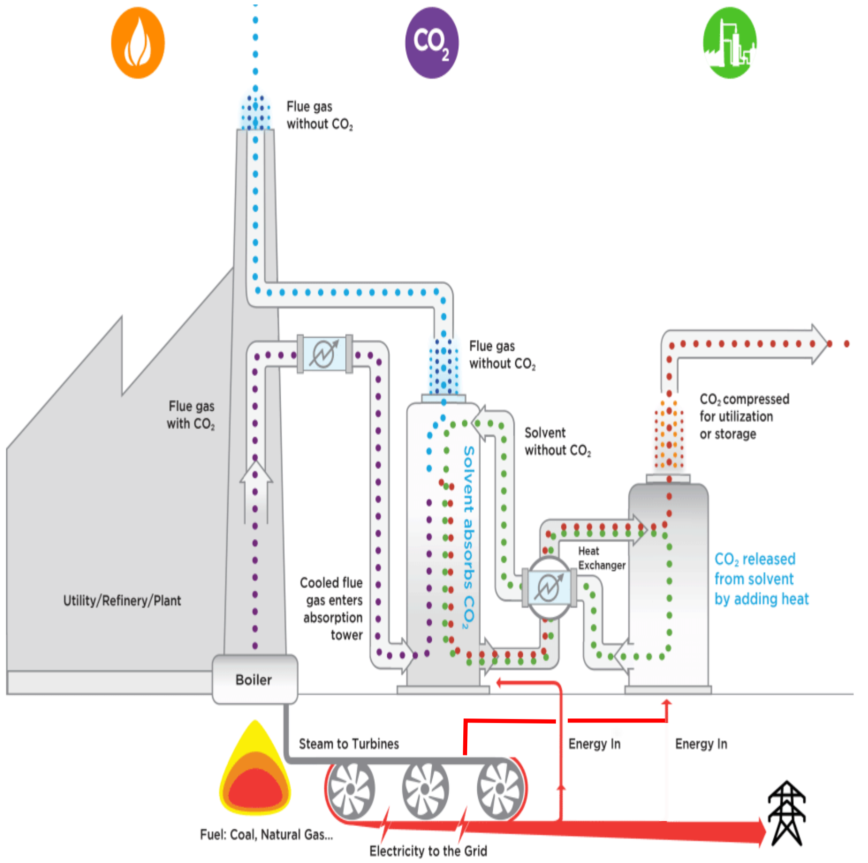
(c) January, 2016*

*The remaining fly ash can be easily removed by soot-blowers.

ION Engineering Advanced Liquid Absorbent System (“LAS”)

Liquid Absorbent System – highly efficient performance:

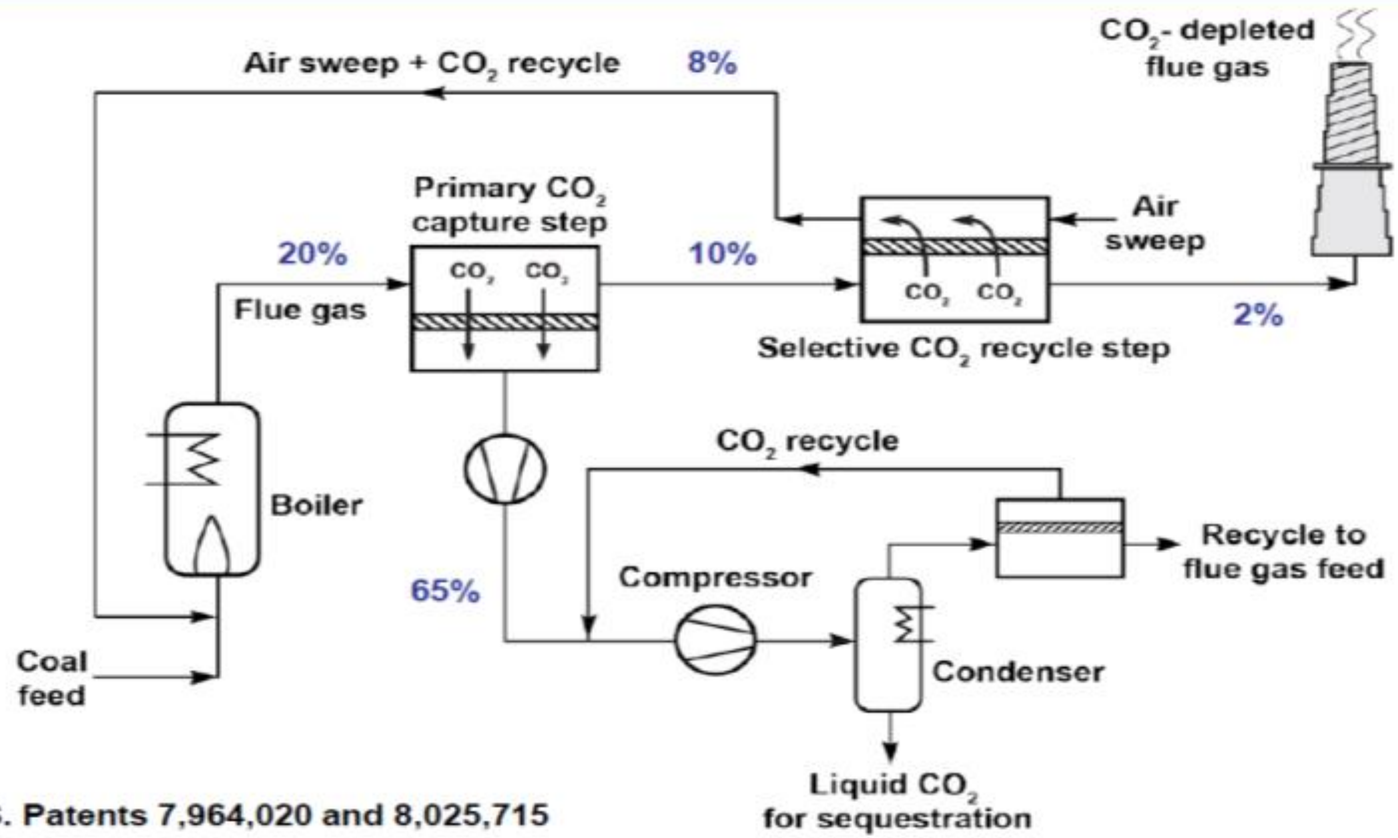
- **Basis of Performance**
  - < 1,090 Btu/lbCO_2 captured (2.5 MJ/kg)
  - Fast kinetics (on par or better than MEA)
  - Working capacity (higher than MEA)
  - Low heat capacity (much lower than MEA)
  - Low tendency for corrosion (much lower than MEA)
- **Reduces CAPEX**
  - Smaller Columns, HXs and Footprint
- **Reduces OPEX**
  - Lower Energy Requirements
  - Less Maintenance
  - Lower emissions
- **Lower Parasitic Load**
- **Scalability**
  - Established Engineering Process



ION Solvent Results vs. Optimized MEA

- Based on an independent Techno-Economic Analysis prepared in 2016, which was compared to optimized MEA technology as the baseline (DOE's BBS case 12) in 2011 dollar basis, ION's Solvent results were:
  - 38% reduction in the incremental capital cost of CO_2 capture;
  - 28% reduction in the incremental annual operating and maintenance costs of CO_2 capture; and
  - \$39-\$45 per Tonne total cost of CO_2 captured,
    - 20% to 30% reduction in cost of CO_2 capture versus base case
    - 32% reduction in differential Cost of Electricity ("COE")

MTR two step membrane CO2 capture process



U.S. Patents 7,964,020 and 8,025,715

Benefits of selective recycle:

- Increases CO_2 concentration going to the capture step, and
- Reduces the fractional CO_2 removal required by the capture step

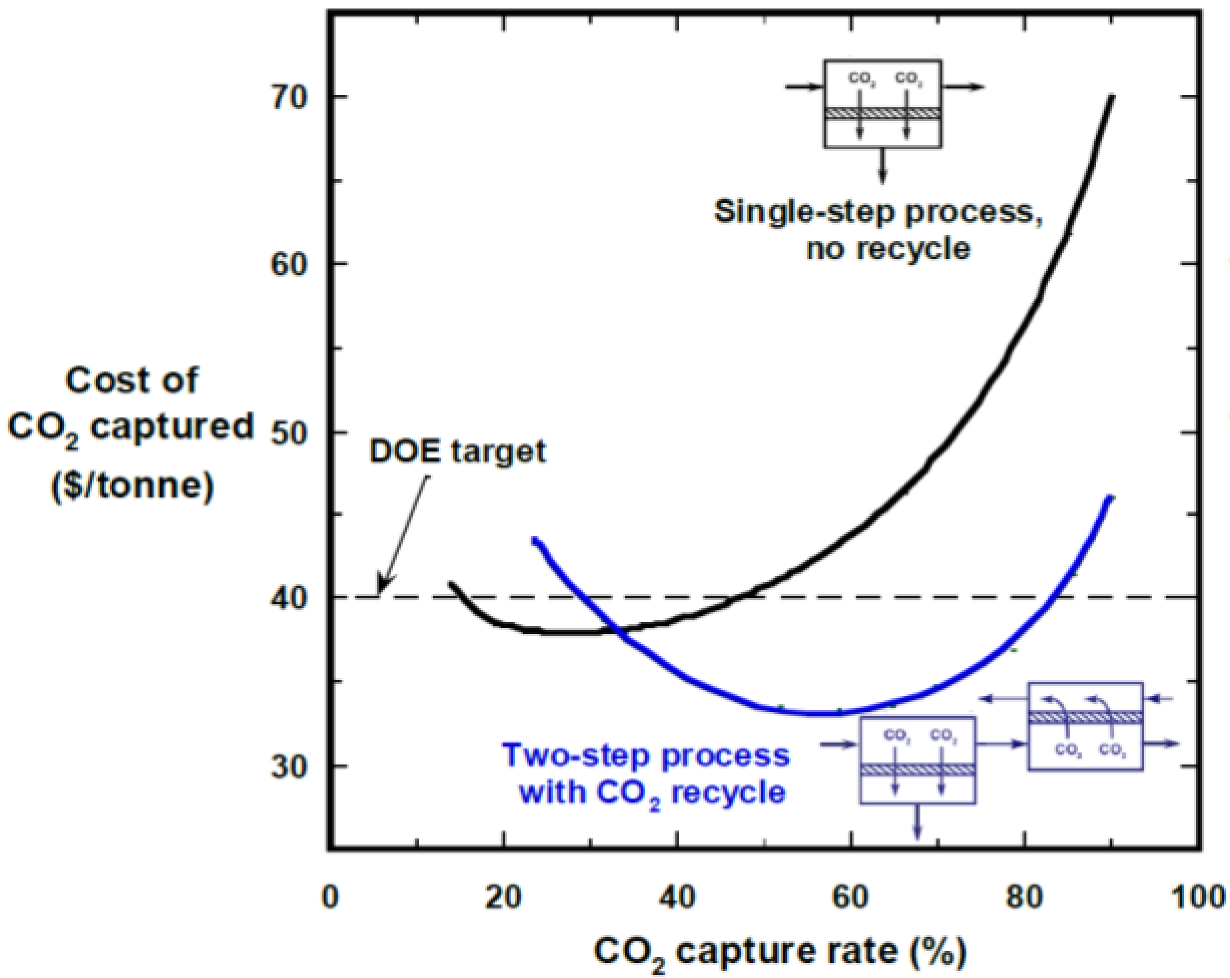
MTR

Advantages of an MTR Membrane Process

- Simple, passive operation with no hazardous chemical handling, emissions, or disposal issues
- Not affected by oxygen, SO_x or NO_x; co-capture possible
- Water use lower than other technologies (recovers H_2O from flue gas)
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Very efficient at partial capture (40-60%)

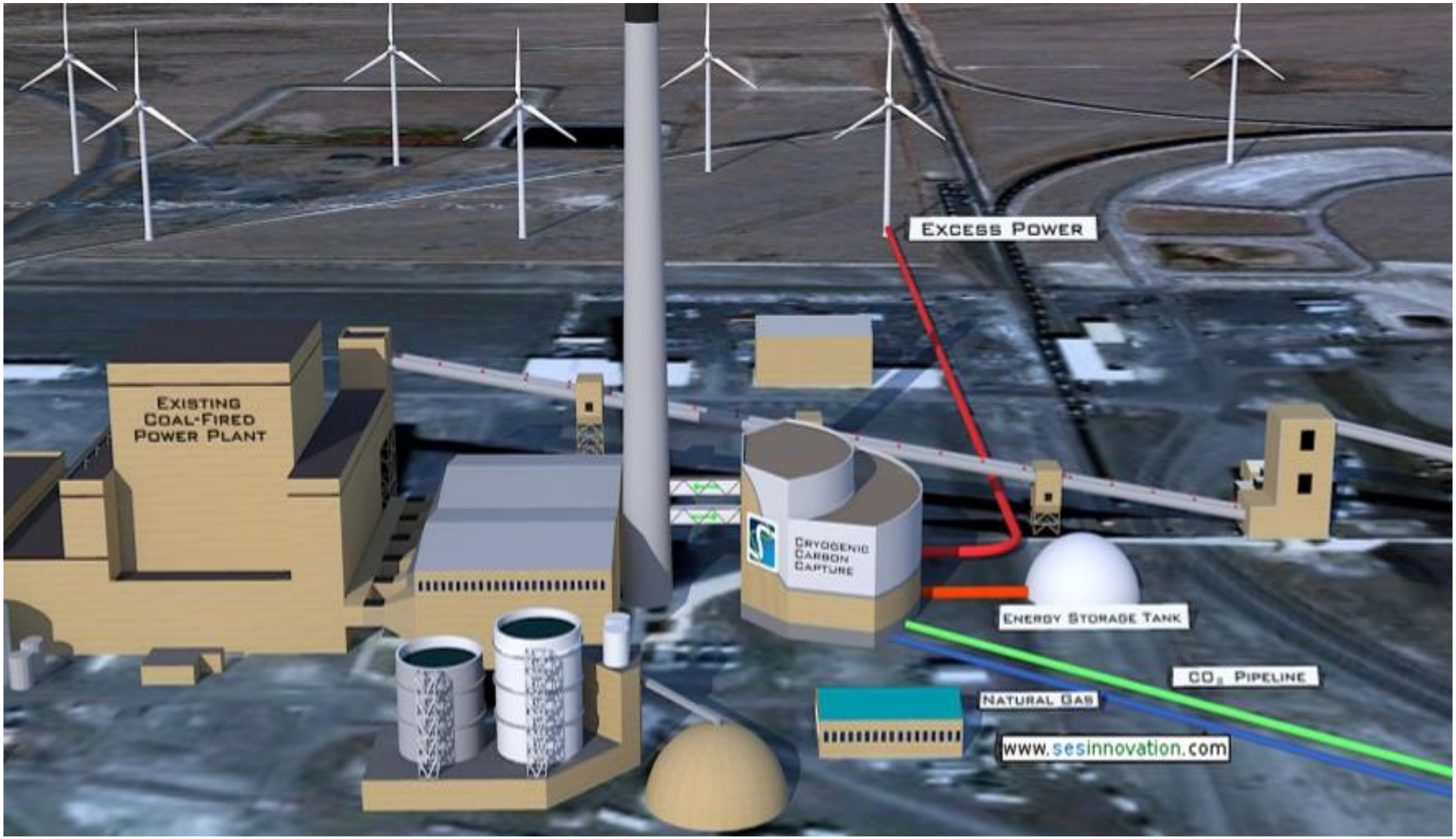
MTR

MTR Membranes are particularly effective at Partial Capture of CO2



- Membranes show a minimum in capture cost
- To meet proposed U.S. EPA emission limits for coal (~30% capture), a simple system without recycle may be preferable

Sustainable Energy Solution Cryogenic Carbon Capture System

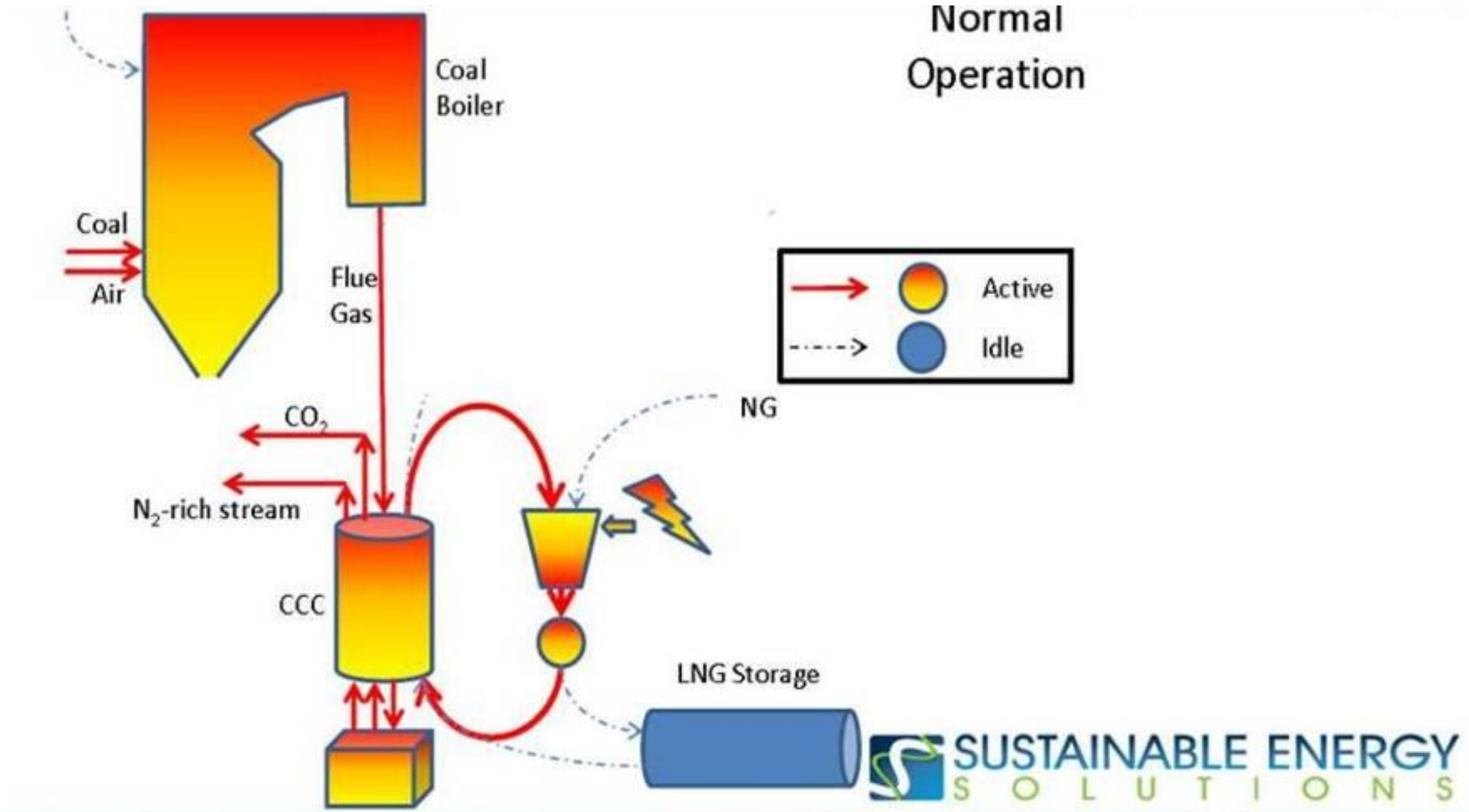


SES CCC Post Combustion Capture of CO_2 Projected estimated cost of $10/ton CO2 to $15/ton CO2

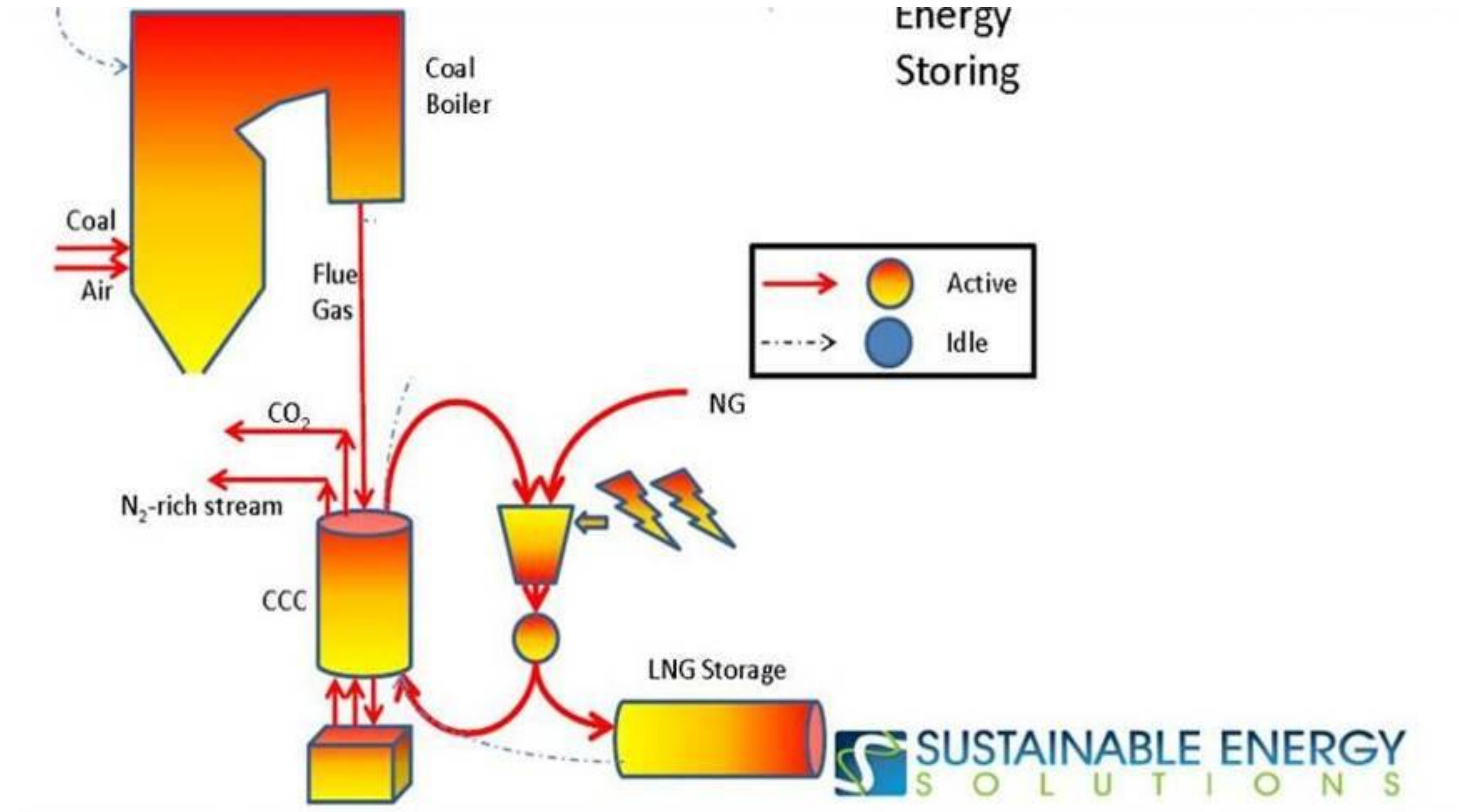
DE sublimating heat exchanger

1 ton of CO2 per day skid sent to a power plant

Sustainable Energy Solution Cryogenic Carbon Capture Post Combustion (DOE ARPA-e funding) Producing Excess LNG During low cost off peak periods with ~30% parasitic loads



Sustainable Energy Solutions Cryogenic Carbon Capture Post Combustion Capture Using stored NLG during Peak Periods to Produce Solid CO_2 with ~0% Parasitic loads



Enviroambient Multi-Pollutant Control and CO_2 Capture Projected Estimated cost of $7 to $10/ton CO2

Multi-pollutant control removal efficiency

>98% SO2

>98%Nox

>99% acid gases

>95% Mercury

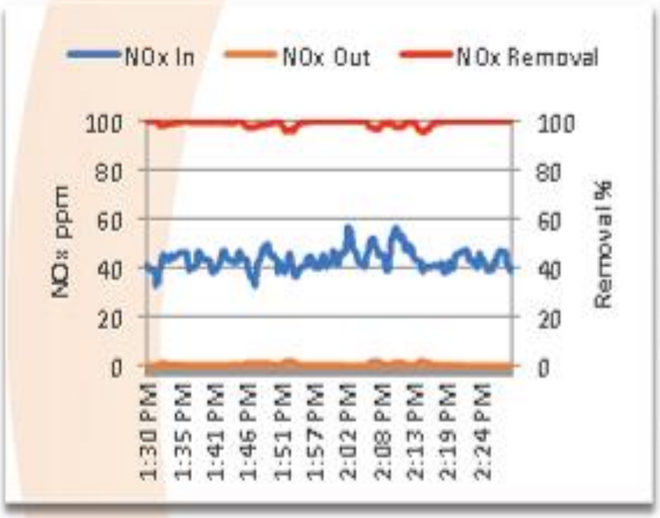
CO2 capture and removal

Low L/G ratio 30%

High L/G ratio >70%

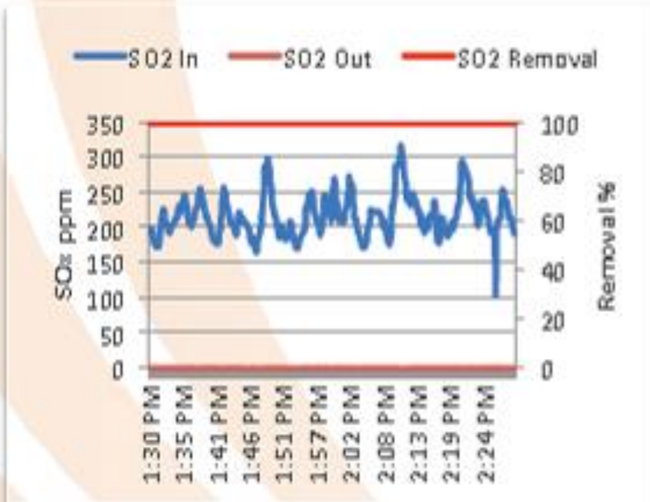
5 MW equivalent Enviroambient multi-pollutant control and carbon capture reaction previously in Louisville, KY

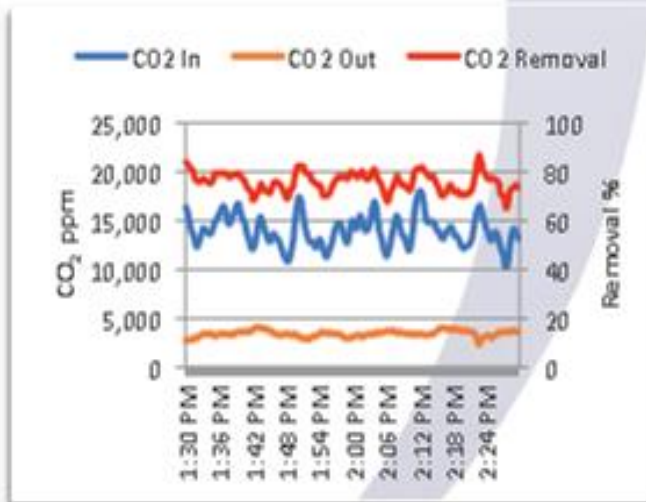
Enviroambient's Multi-Pollutant and CO_2 Removal Process



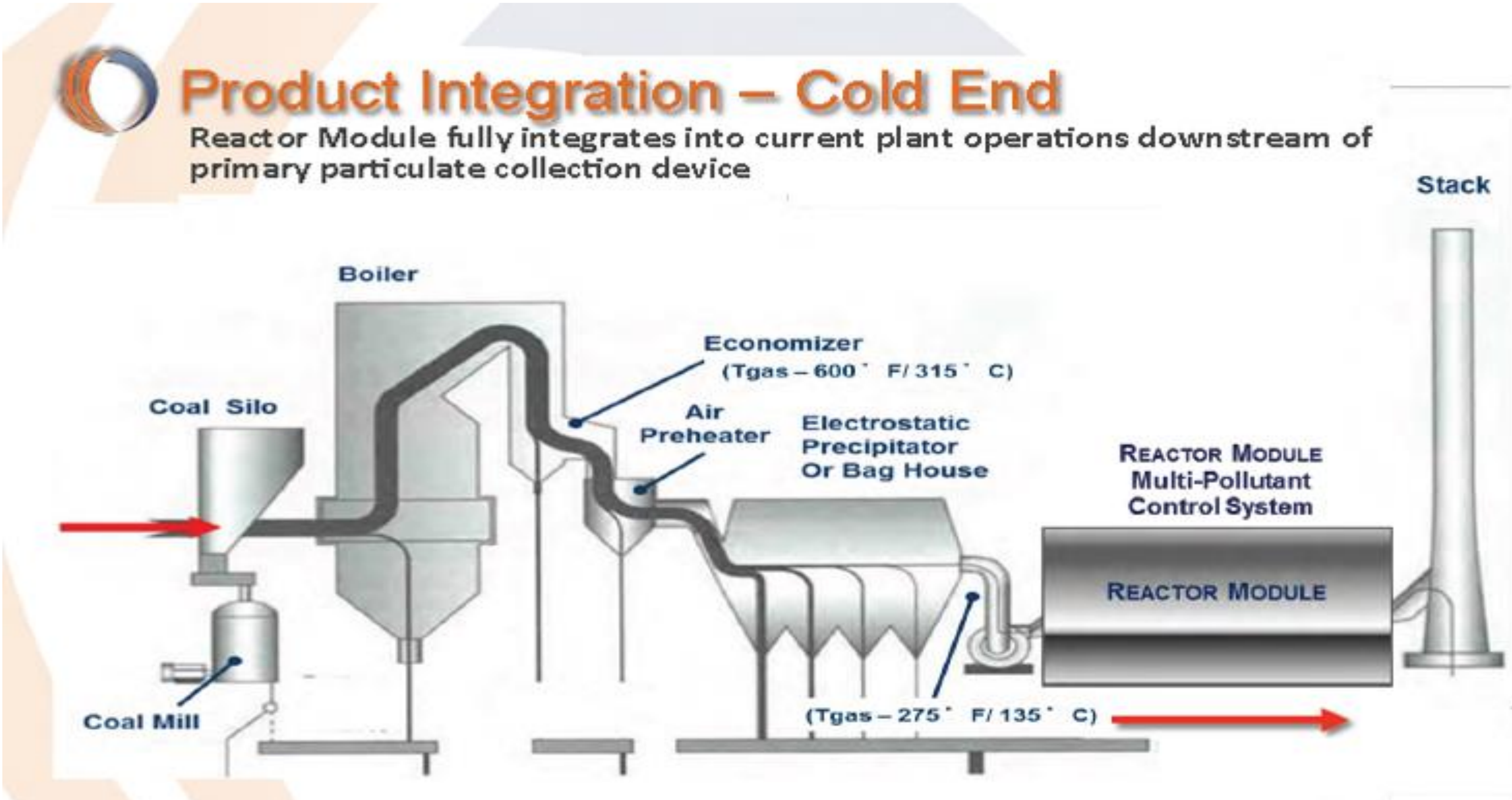
Operating Conditions (8/14/2012)		
	Inlet (ppm)	Outlet (ppm)
Gas Temp	257°F (125°C)	89°F (32°C)
NOx	43.36 (ppm)	0.44 (ppm)
SO_2	216.58 (ppm)	0.00 (ppm)
CO_2	13,865 (ppm)	3,352 (ppm)

Eastern Bituminous Coal Ultimate Analysis	
Carbon	69.90%
Hydrogen	4.70%
Oxygen	6.40%
Nitrogen	1.20%
Sulfur	2.20%
Ash	13.20%
Moisture	2.40%
Heating Value	12,644 Btu/lb



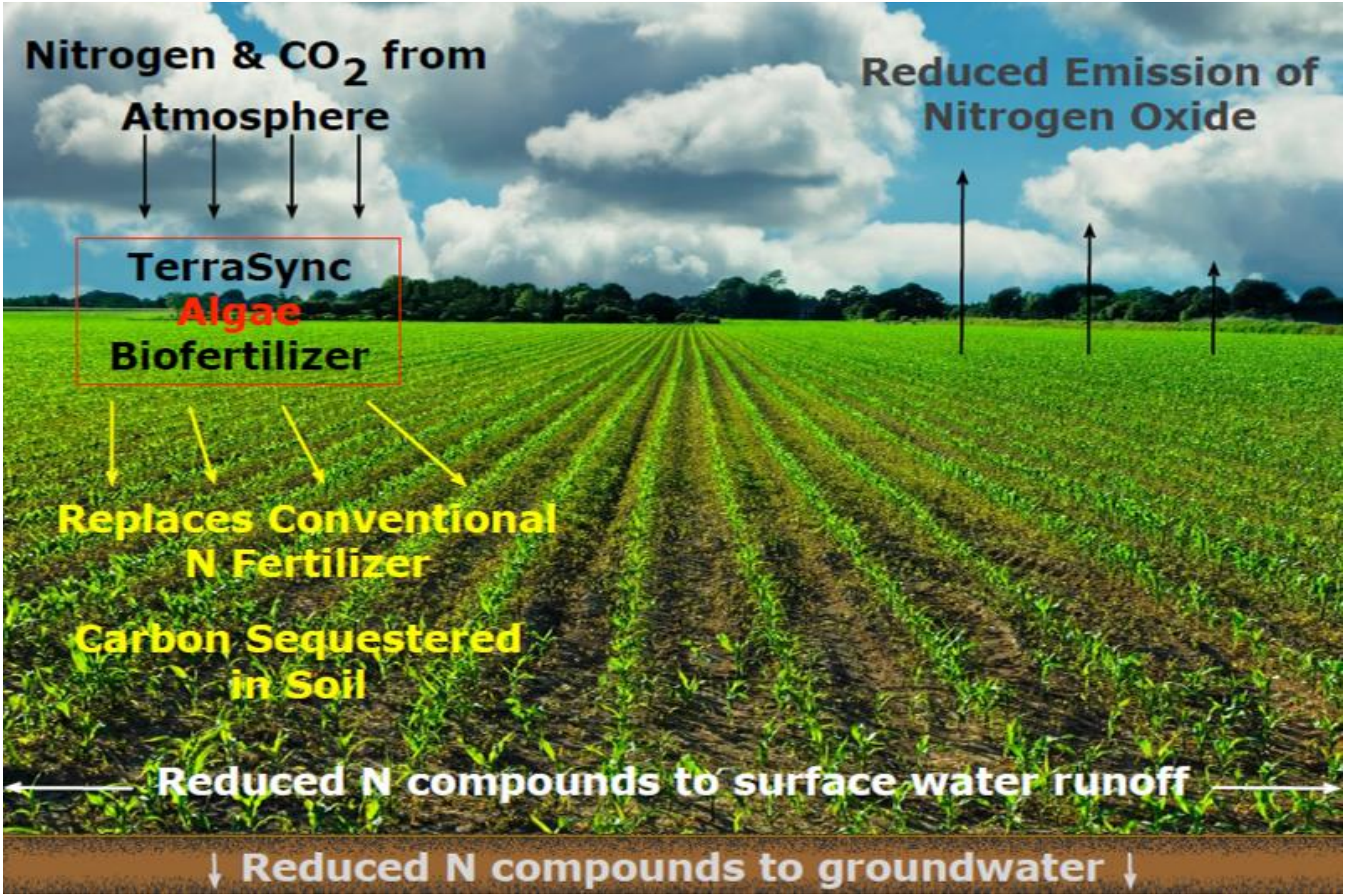


Enviroambient's Multi-Pollutant and CO_2 Removal Process



Enviroambient is looking for a host site to demonstrate a 25 MW CO2 capture reactor

Acelergy Algae Biofertilizer Carbon Offsets and Terrestrial Sequestration



Success of Acelergy's Blue Green Algae (Cyano Bacteria) Infusion in the Ground - Use Coop model with Farmers within G&T Service Territory?

200 Acre Algae Biofertilizer Demonstration Arizona Farm

Del Monte Quality

Yosemite Melons	
Germination	2X
Early Growth	2.5X
Plant Size & Density	3X
Early Melon Maturity	2X
Mature Melon Size	1.4X
Mature Melon Weight	1.5X
Taste (blind panel test)	14:1

Possible CO_2 Utilization Options

- Enhanced Oil Recovery (EOR) to pay $15/ton up to X % of three times the price for oil (assuming joint venture development of an old oil field)
- Chemical/Catalytic conversion of CO_2 + methane + microwave heating of iron and nickel catalysts yielding syngas (to be converted to liquid fuels) and high value chemicals

Why CO_2 for EOR?

Benefits of CO_2 injection for EOR :

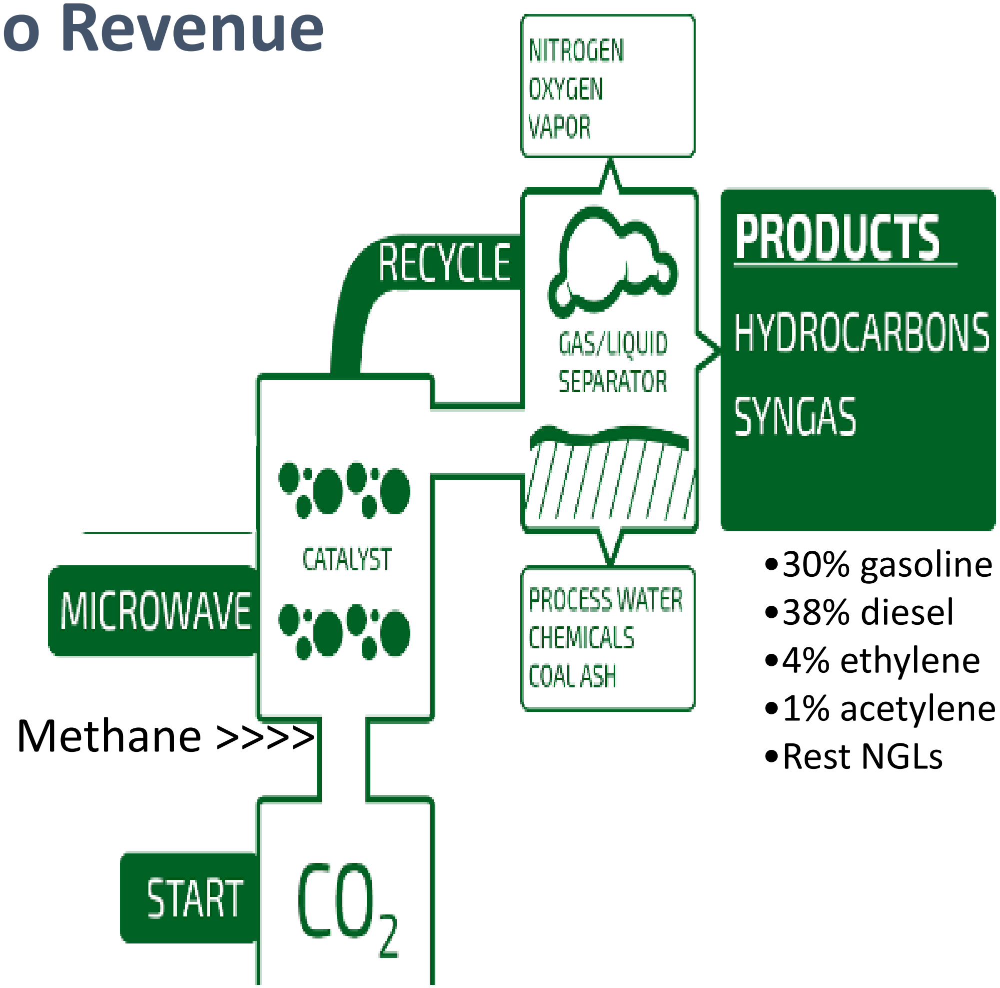
1. CO_2 foam increases fracking length
2. CO_2 decreases formation swelling
3. CO_2 hastens well bore cleanup
4. CO_2 has superior leak-off control
5. CO_2 increases well production
6. CO_2 requires less horsepower and electricity than Injection of nitrogen
7. CO_2 reduces water and corrosion
8. One ton of CO2 can produce 3 to 4 barrels of oil worth:
   - $180 to $240 for oil at $60/barrel
   - $300 to $400 for oil at $100/barrel

Chemical Catalytic conversion of CO_2 to Liquid Fuels

Converting Liability to Revenue

- Boudouard Reaction CO2 to CO
- Reformation of methane

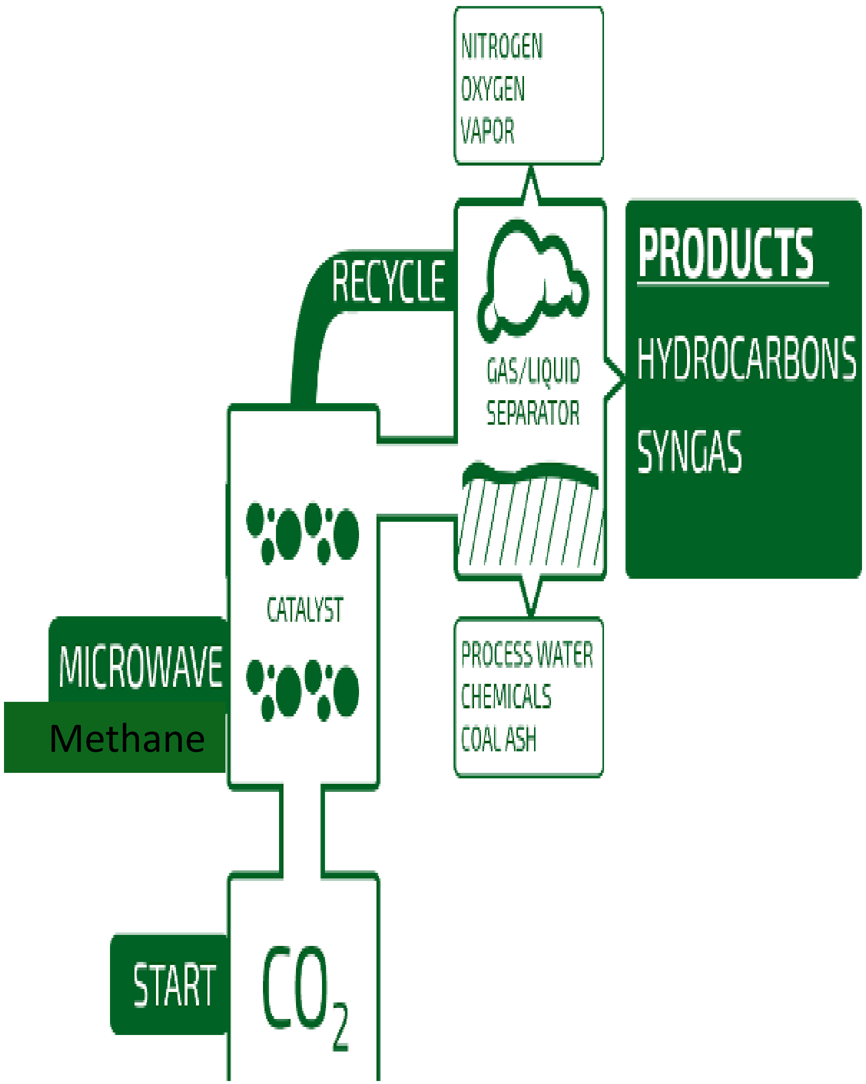
•Microwave heating and catalytic reaction10 kg/hr. of CO2 test by DOE NETL was successful converting CO2 plus methane into H2 and CO syngas plus microwave and iron oxide catalyst



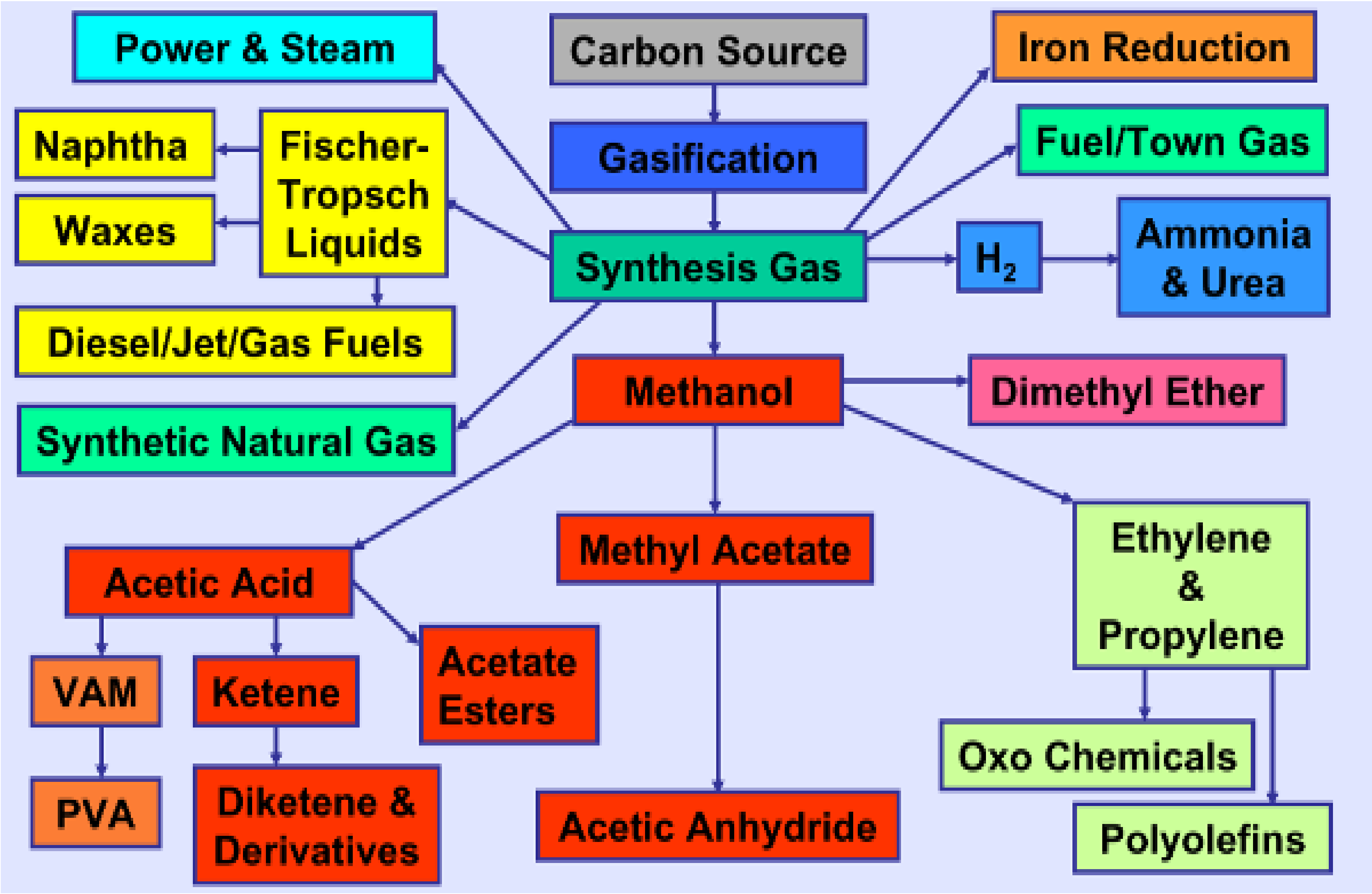
- 30% gasoline
- 38% diesel
- 4% ethylene
- 1% acetylene
- Rest NGLs

Chemical/Catalytic Conversion of CO2 to liquid Fuels and Chemicals

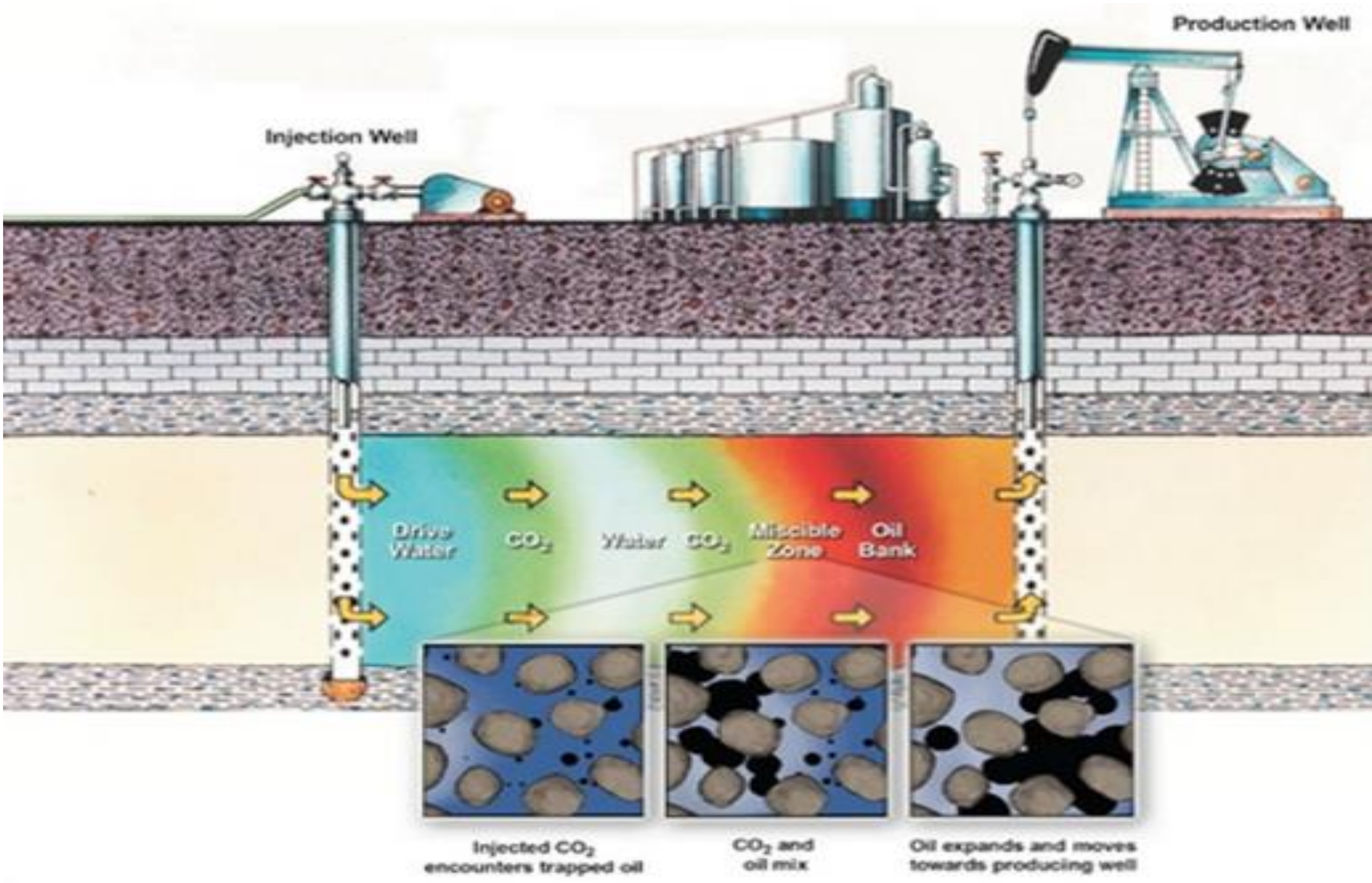
- Testing Completed for a 1/2 tph with 50 kW of microwave energy injected into a chemical/catalytic reactor at Hazen Labs in Denver https://www.youtube.com/watch?v=ZqkWlbiFOw8
- Engineering design has begun for a 20 MW coal equivalent 20 TPH CO2 chemical/catalytic reactor with 10 X 100 kW solid-state microwave emitters to be operational in 18 months



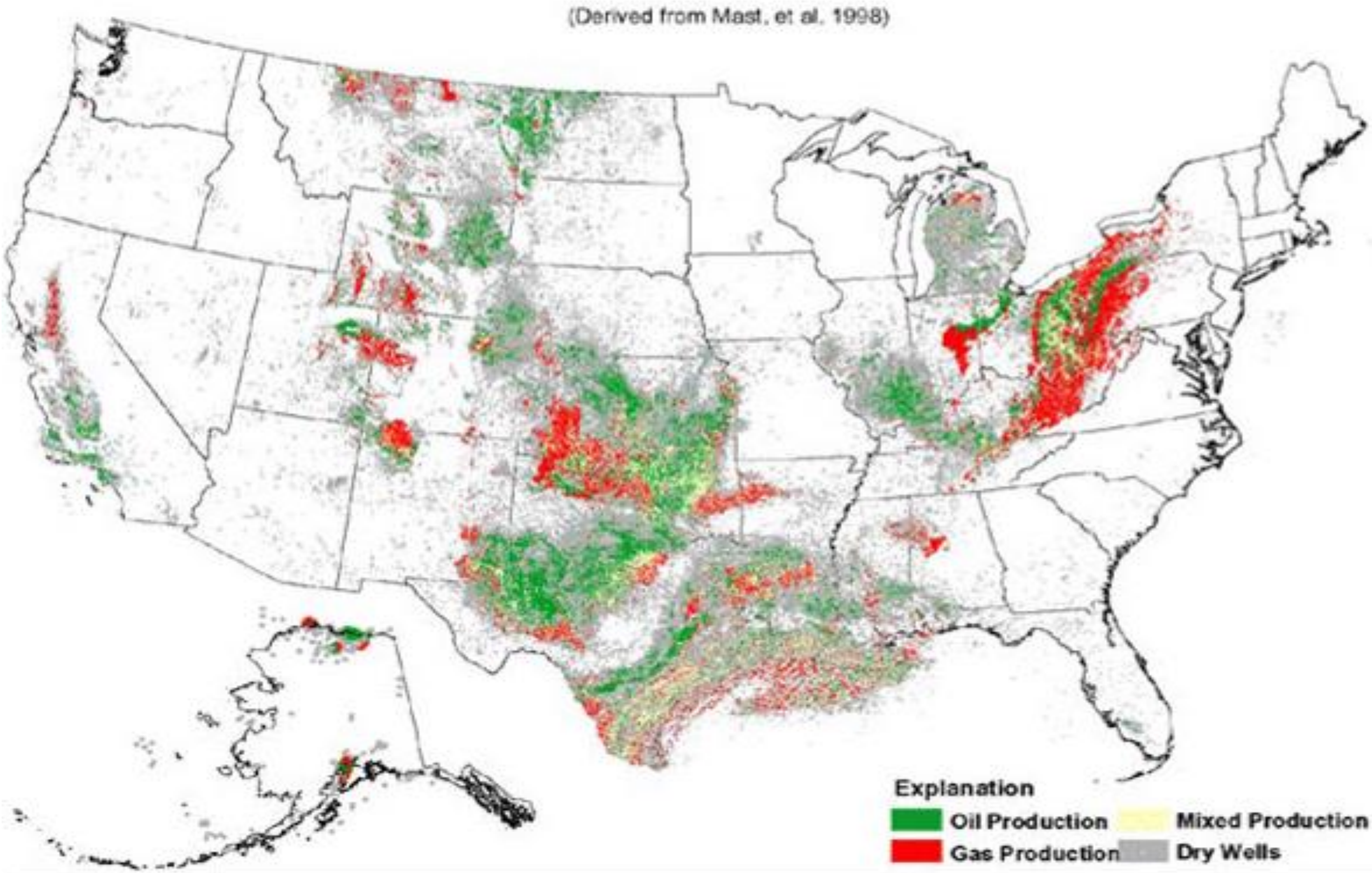
Use of Syngas from HTCE and Oxycombustion



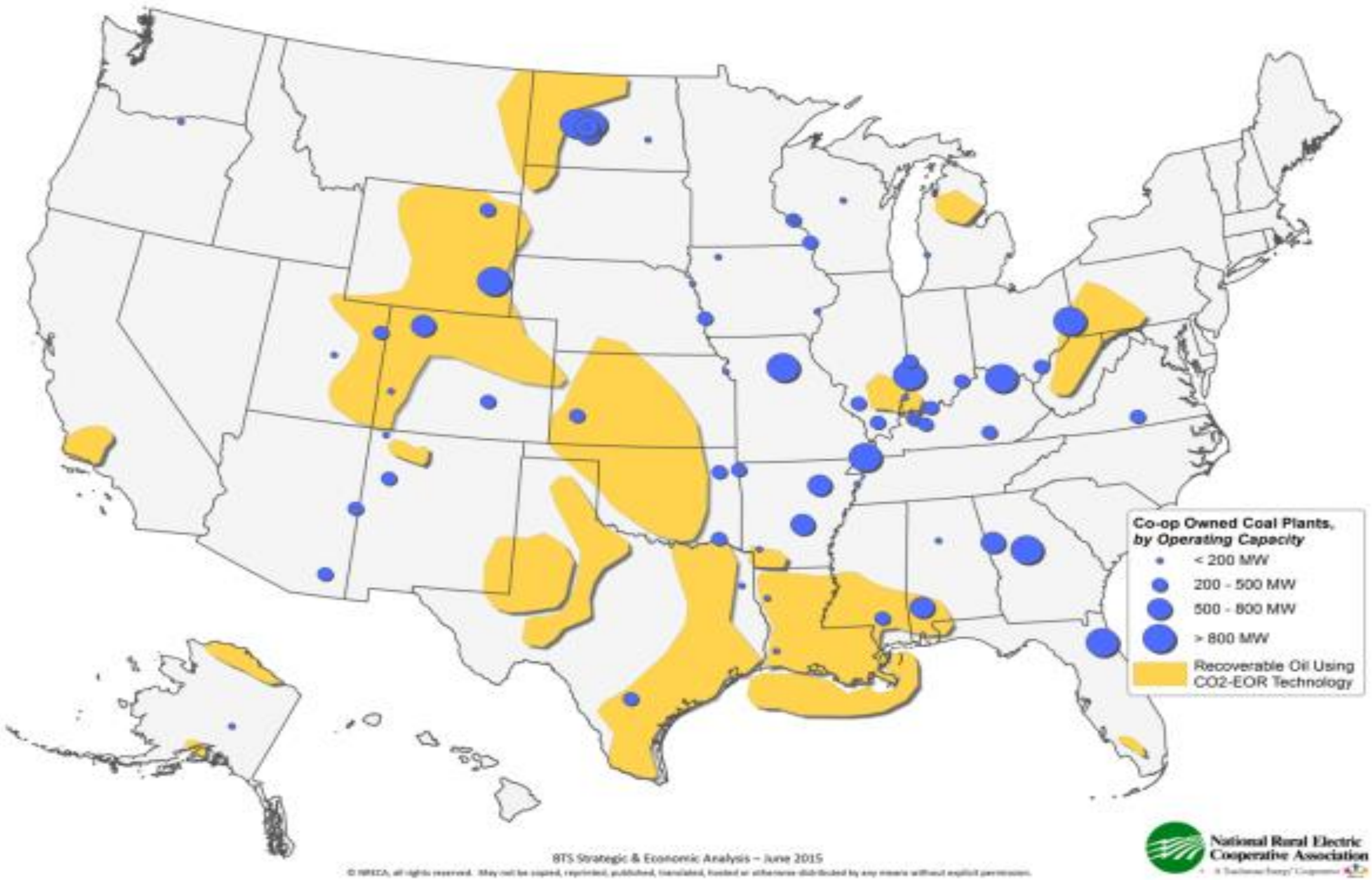
Expanding Market for CO_2 Used for Enhanced Oil Recovery (EOR)



Oil and Natural Gas Production in the United States



Co-op Owned Coal Plants versus Oil Fields that could Recover Oil using CO2



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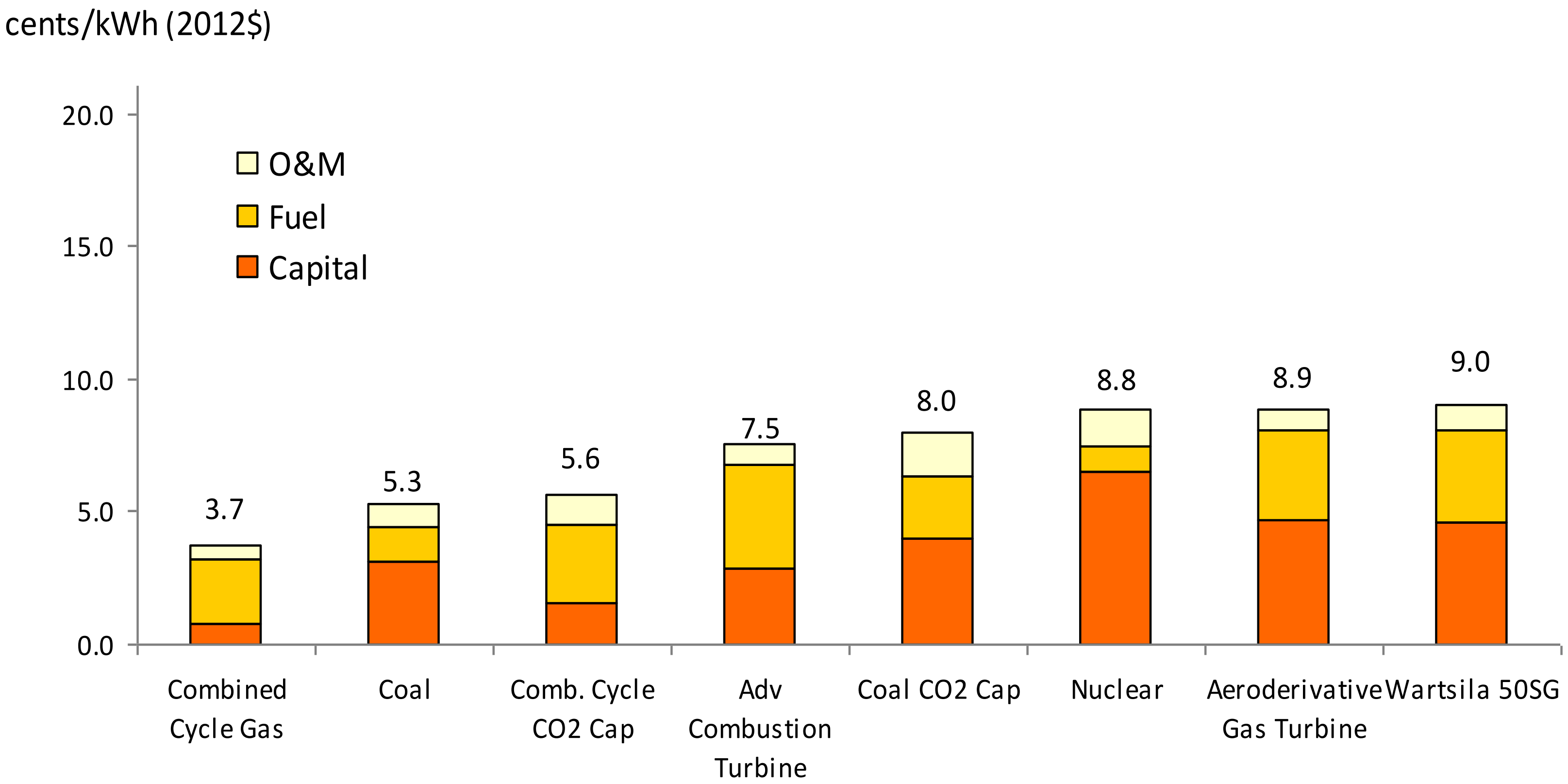
4. CO_2 has superior leak-off control
5. CO_2 increases well production
6. CO_2 requires less horsepower and electricity than Injection of nitrogen.
7. CO_2 reduces water and corrosion

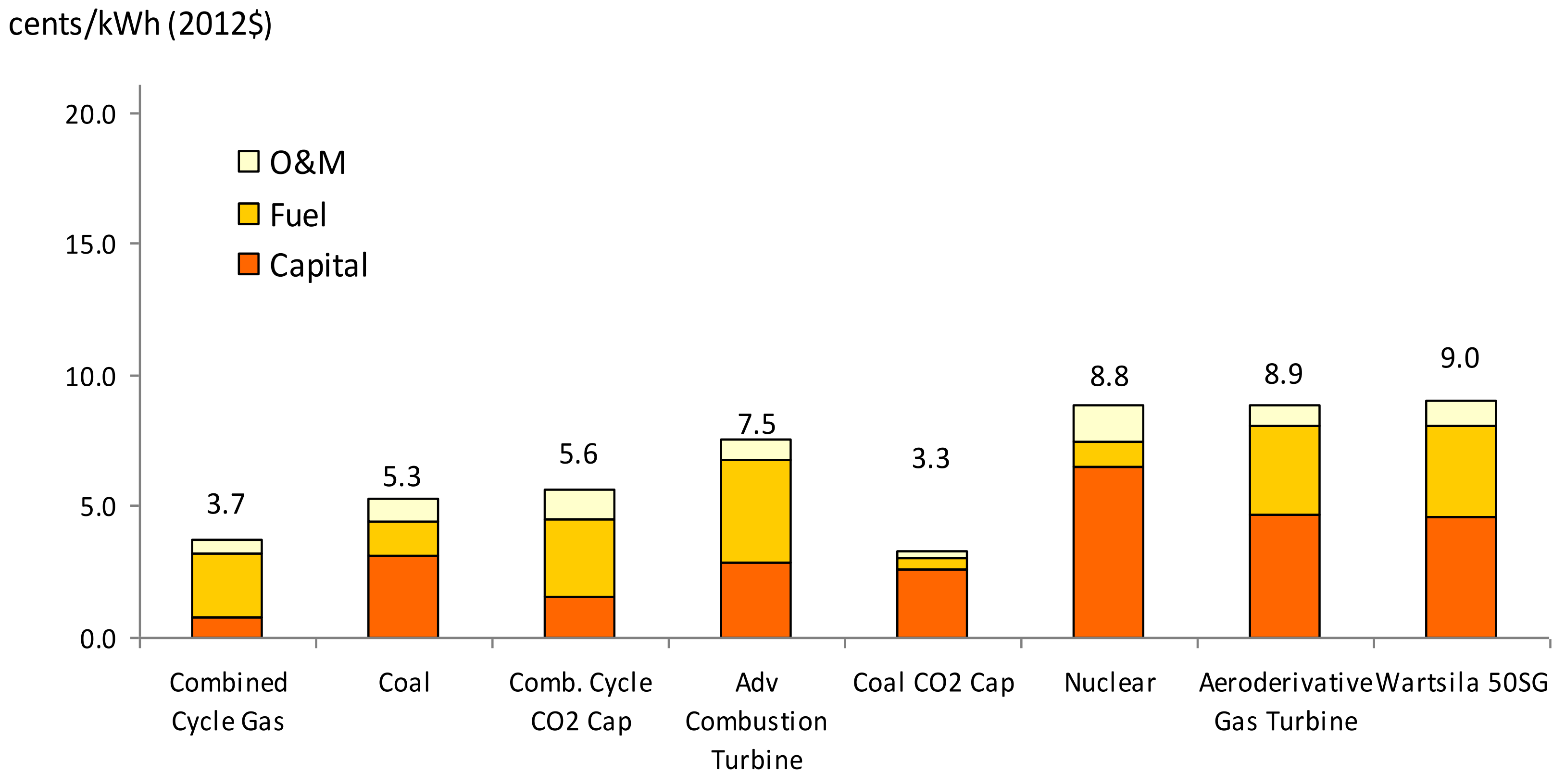
Possible Market for CO2 for Enhanced Oil Recovery (EOR)

- **Assuming oil is at $100/bbl**
  - **Up to 4 million bbl of additional oil can be recovered each year (about 31% of crude oil imports)**
  - **Another 67 to 137 billion bbl of additional recoverable oil (proved reserves are only 25 billion bbl)**
  - **18 to 43 billion tons of CO_2 would be needed (93 to 222 GW of base load coal for 30 years) with coal now emitting about 1.6 billion tons per year.**
  - **One ton CO_2 yields 3 bbl oil (worth $300/ton CO_2)**
  - ***Big issue now with EPA permitting of sequestering CO_2 under Title 6 and not Title 2 (for current natural sources of CO_2 for EOR).***

Levelized Cost of Electricity with and without capture of CO_2 New Generating Plant for Electric Cooperatives



Levelized Cost of Electricity with and without CO2 capture
New Generating Plant for Electric Cooperatives
Assume Low Cost CO2 capture at $15/ton and Sale of CO2 at $35/ton



NRG COSIA carbon X PRIZE forecast of possible products

- Graphene nano-platelets (to serve as an additive for high electrical, mechanical, and chemical performance in concrete, polymers, coatings, and asphalt)
- Enhanced Concrete (enhanced concrete strength and value)
- formic acid (projecting production of formic acid at 5 times lower cost),
- high-protein animal feed, fertilizer (ammonium or potassium sulfate and ammonium or potassium nitrate);
- dry ice for energy storage, cooling and fuel for a ram jet engine;
- value added organic chemicals; biodiesel and solid biofuel;
- health supplements, toothpaste, paint and fertilizers;
- treating Acid Rock Drainage or ARD into stable solid metal carbonates and converting a non-metal pollutant into a sellable product;
- methanol and micro-foamed bio-composite boards; graphite and Carbon nanotubes; methanol;

NRG COSIA carbon X PRIZE forecast of possible products

- valuable carbonate feedstocks using an alkali base;
- oxygen; 3D- printed concrete replacement building material;
- gas and liquid fuels; acetic acid (solvents, food, etc.);
- synthesis gas; fuels and chemicals; convert CO2 back into coal and graphene;
- high-strength polymers;
- CO2 biomass for coastal/wetlands stabilization using a closed loop high pressure, high temperature process to produce bio products (to shore up coastal wetlands) and acids;
- dimethyl ether (DME – a clean burning fuel or chemical feedstock);
- fish food and biomass;
- essential biochemical building blocks/amino acids;
- higher coal plant efficiency with less emissions;
- acetone (cleaning agent, solvents, cosmetics, etc.)
- integrating sugar and CO2 gas fermentation

We're getting there!

Kemper County IGCC – Mississippi Power/Southern Co.

We’re getting there!

Boundary Dam – SaskPower, Saskatchewan

Questions?

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