Carbon Capture and Storage (CCS) and Potential CO_2 Solutions

HTWI
High Tech Workforce Initiative

MARICOPA COMMUNITY COLLEGES®

National Science Foundation
WHERE DISCOVERIES BEGIN

Hosted by MATEC Networks

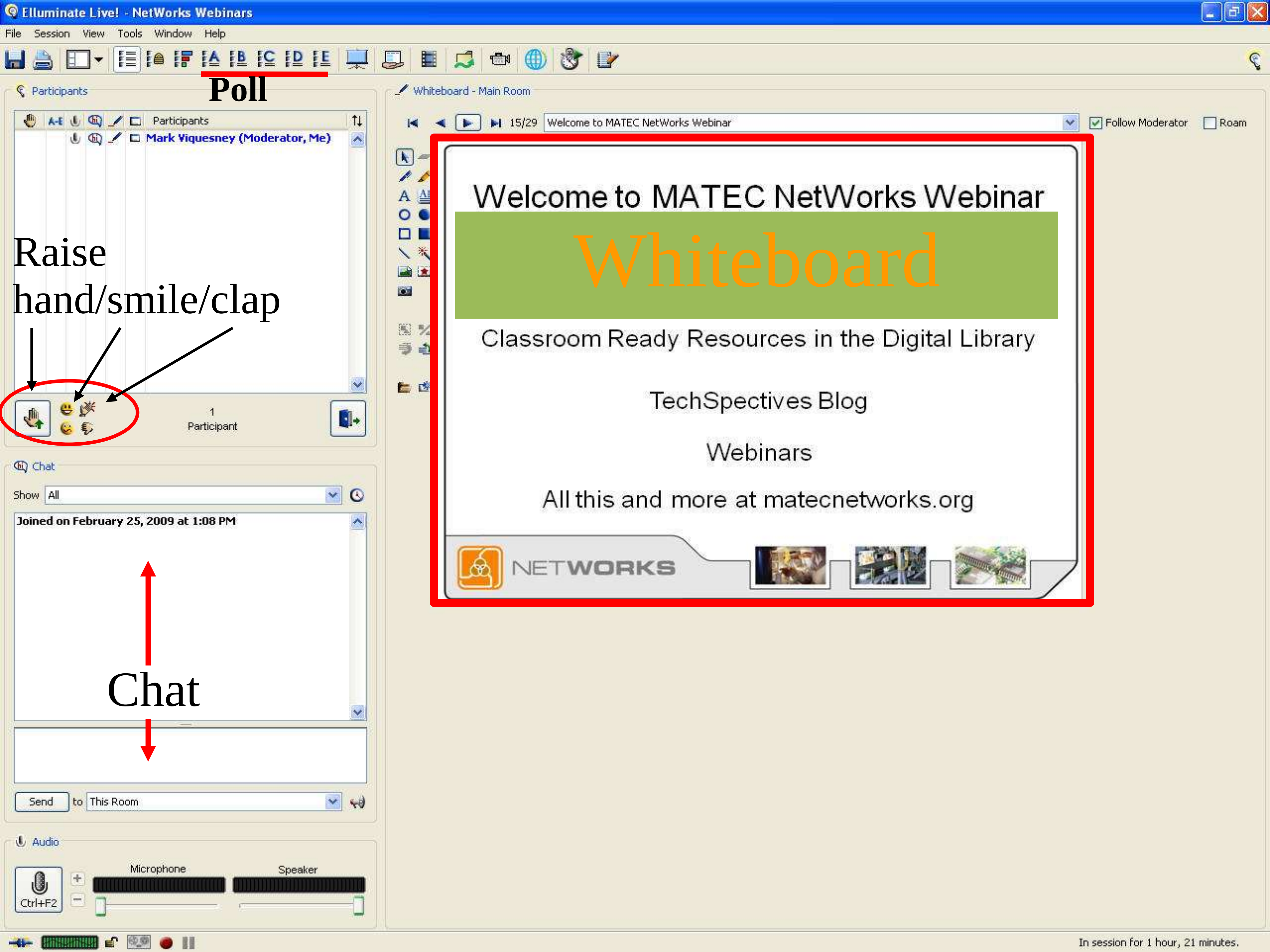
www.matecnetworks.org

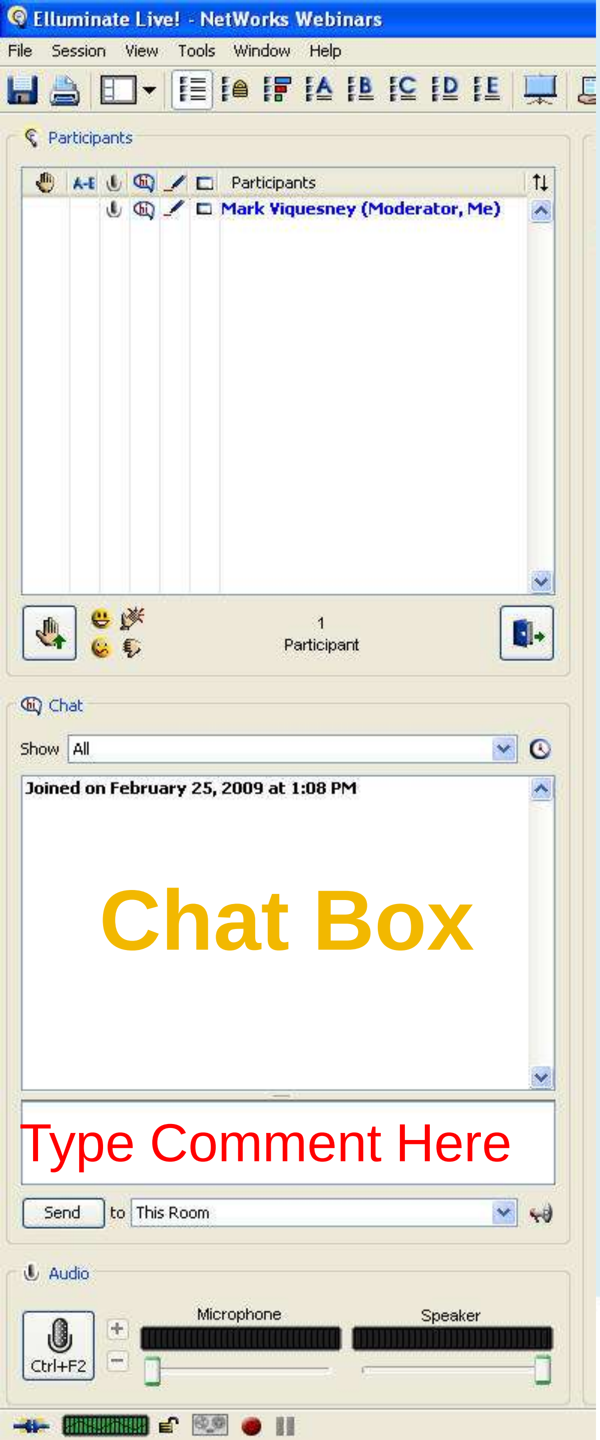
Funded, in part by a grant from the
National Science Foundation
DUE 1003542

HTWI is a part of
Center for Workforce Development
a member of the
Division of Academic and Student Affairs at the
Maricopa Community Colleges.

Funded, in part, by a grant from the National
Science Foundation.
DUE-1003542

HTWI
High Tech Workforce Initiative


Elluminate Live! - NetWorks Webinars
File
Session
View
Tools
Window
Help
Poll
Participants
Participants
Mark Viquesney (Moderator, Me)
Raise hand/smile/clap
1
Participant
Whiteboard - Main Room
15/29
Welcome to MATEC NetWorks Webinar
Follow Moderator
Roam
Welcome to MATEC NetWorks Webinar
Whiteboard
Classroom Ready Resources in the Digital Library
TechSpectives Blog
Webinars
All this and more at matecnetworks.org
NETWORKS
Chat
Show
All
Joined on February 25, 2009 at 1:08 PM
Chat
Send
to
This Room
Audio
Microphone
Speaker
Ctrl+F2
In session for 1 hour, 21 minutes.

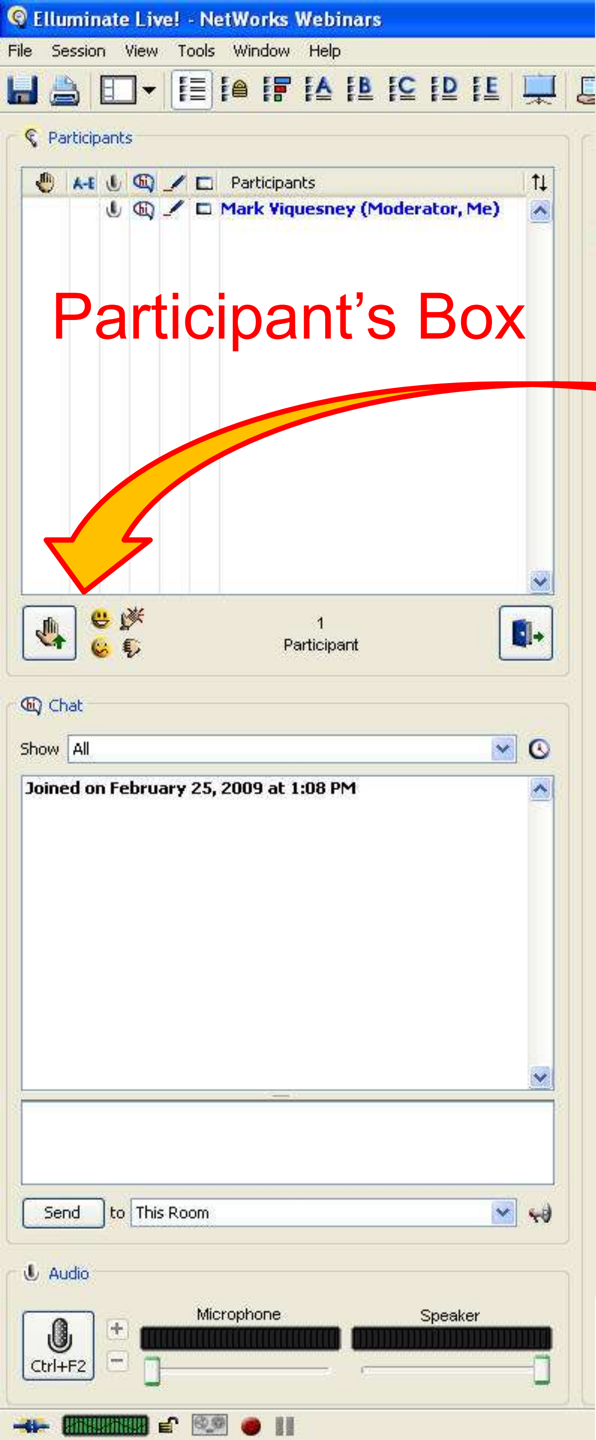


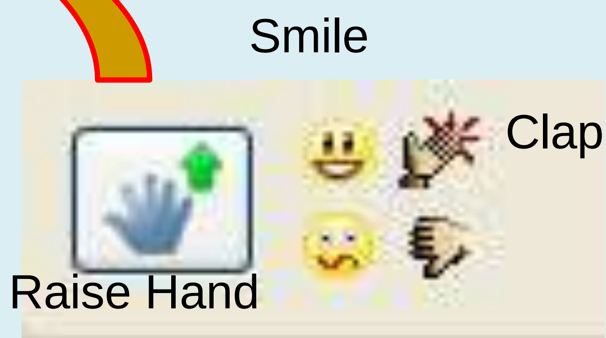
Chat Box

In the **Chat Box**,
please type the name of
your school or organization,
your location,
and how many people are
attending with you today.

HTWI
High Tech Workforce Initiative

Participant's Box





Let the presenter know if you like what they say with a smile or clap. Raise a hand if you have a question – and then type it into the chat box.

HTWI
High Tech Workforce Initiative

HTWI Webinar Presenters

www.globe-net.com/media/261542/co2from_stack.jpg

www.rsc.org/.../co2-chimney-410_tcm18-187444.jpg

Brad Bates
Chemistry Faculty
Chandler Gilbert Community College – Williams Campus
7360 E. Tahoe Avenue
Mesa, AZ 85212
(480) 988-8996
brad.bates@cgcmail.maricopa.edu

HTWI
High Tech Workforce Initiative

www.globe-net.com/media/261542/co2from_stack.jpg

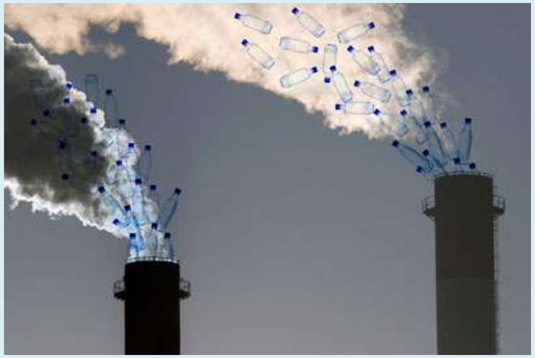
Carbon Capture and Storage with Potential CO_2 Solutions

Brad Bates

Chemistry Faculty

Chandler-Gilbert Community College

January 21, 2011



www.rsc.org/.../co2-chimney-410_tcm18-187444.jpg

HTWI

High Tech Workforce Initiative

Agenda

- Introduction
- Electrical Power Consumption & CO_2
- Making Electricity and Capturing CO_2
- Managing CO_2
  - CO_2 as a commodity
  - Carbon Sequestration
  - Recycling CO_2 into commercial products

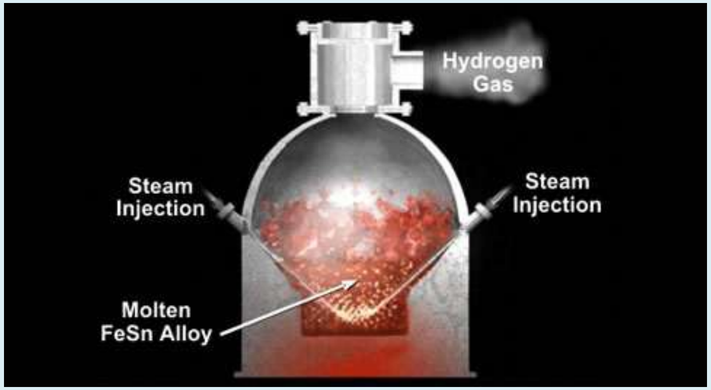
HTWI & Diversified Energy

www.blogcdn.com/.../01/diversified-energy.png

- Diversified Energy Corporation is a privately held company specializing in promising alternative and renewable energy technologies.
- HTWI – High Tech Workforce Initiative is led by the Center for Workforce Development in MCCCD and is funded by the National Science Foundation.

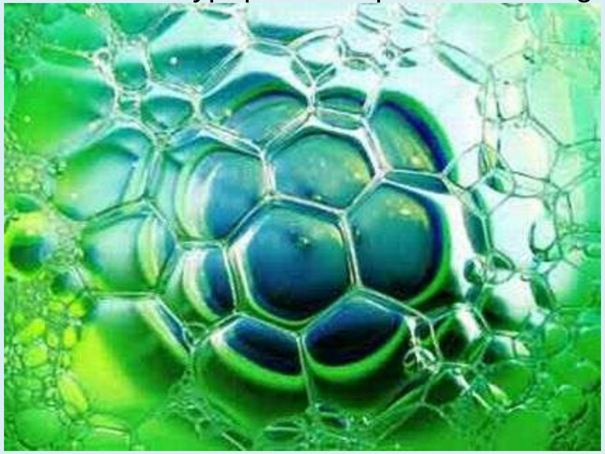
Diversified Energy Projects

Advanced gasification techniques with feedstock flexibility targeted for industrial syngas applications and liquid fuels production.



thefraserdomain.typepad.com/photos/uncategori…

Algal biomass cultivation system that is scalable and economical for fuel production.



www.instablogsimages.com/.../algaejpg_5638.jpg

HTWI High Tech Workforce Initiative

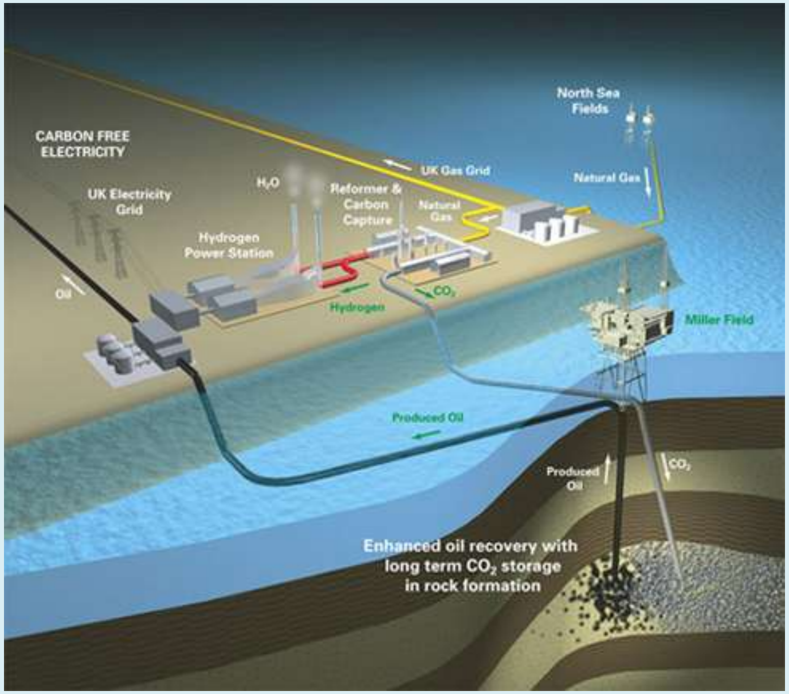
Diversified Energy Work

Study Parasitic load of carbon capture in post-combustion, pre-combustion and oxy-fuel combustion power plants power plants.

sitemaker.umich.edu/.../files/picture1.jpg

Diversified Energy Work

Determine the potential business opportunities in carbon sequestration for Diversified Energy.



earth2tech.files.wordpress.com/2008/01/csc1.jpg

HTWI
High Tech Workforce Initiative

Diversified Energy Work

Briefed company on HR 2454 “The American Clean Energy and Security Act of 2009” as the bill worked its way through the Congress.

www.visitingdc.com/images/capitol-building-pi..

HTWI
High Tech Workforce Initiative

www.wormgeek.com/.../uploads/2010/06/trees.jpg

Curriculum

www.brightstarsolar.net/wp-content/uploads/20..

- How much energy does a student use in a day, month or year?

HTWI
High Tech Workforce Initiative

www.wormgeek.com/.../uploads/2010/06/trees.jpg

Curriculum

www.brightstarsolar.net/wp-content/uploads/20..

- How much energy does a student use in a day, month or year?
- How is electricity made from coal?

HTWI
High Tech Workforce Initiative

www.wormgeek.com/.../uploads/2010/06/trees.jpg

Curriculum

www.brightstarsolar.net/wp-content/uploads/20..

- How much energy does a student use in a day, month or year?
- How is electricity made from coal?

- How is CO_2 captured in this process?

HTWI
High Tech Workforce Initiative

www.wormgeek.com/.../uploads/2010/06/trees.jpg

Curriculum

www.brightstarsolar.net/wp-content/uploads/20..

- How much energy does a student use in a day, month or year?

- How is electricity made from coal?
- How is CO_2 captured in this process?
- What is carbon sequestration?

HTWI
High Tech Workforce Initiative

www.wormgeek.com/.../uploads/2010/06/trees.jpg

Curriculum

www.brightstarsolar.net/wp-content/uploads/20..

- How much energy does a student use in a day, month or year?

- How is electricity made from coal?
- How is CO_2 captured in this process?
- What is carbon sequestration?
- How can carbon be reused or recycled?

HTWI
High Tech Workforce Initiative

Waste to Energy – Potential Solutions

Student Comments

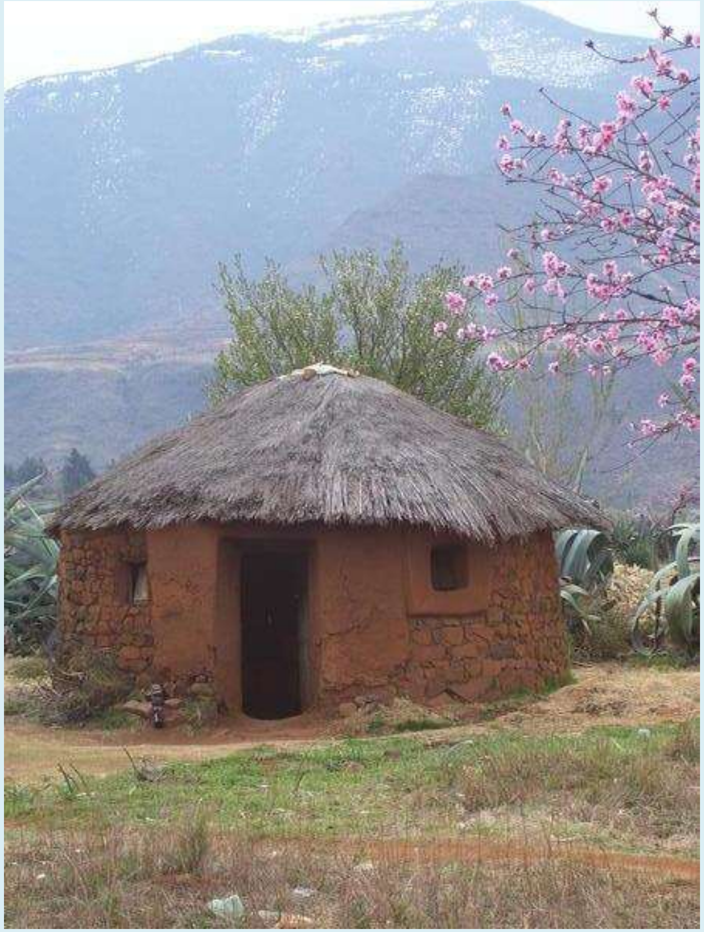
blog.mapawatt.com/.../2009/11/Al_gore_earth.jpg

"I get the whole global warming / climate change thing, you got my attention, but what now?"

HTWI
High Tech Workforce Initiative

Student Comments

www.hainaultforest.co.uk/CharcoalBurnHut6.JPG



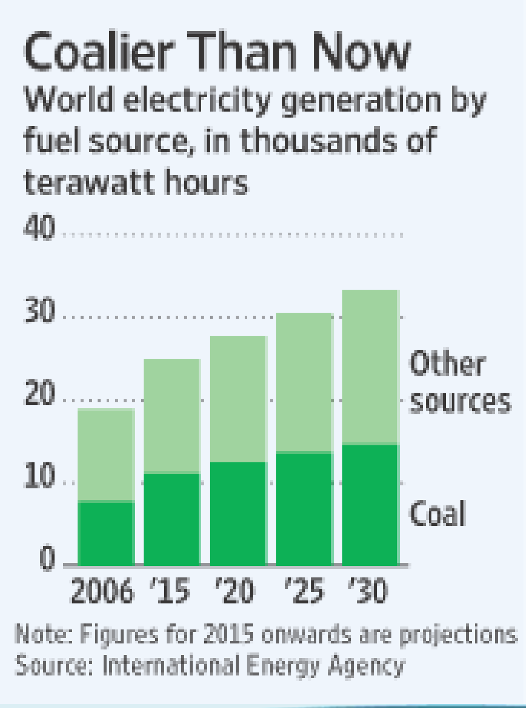
photos.travelblog.org/Photos/18100/89745/f/56...

"There must be something I can do about climate change without having to live in a grass hut."

HTWI
High Tech Workforce Initiative

What's the Basic Problem?

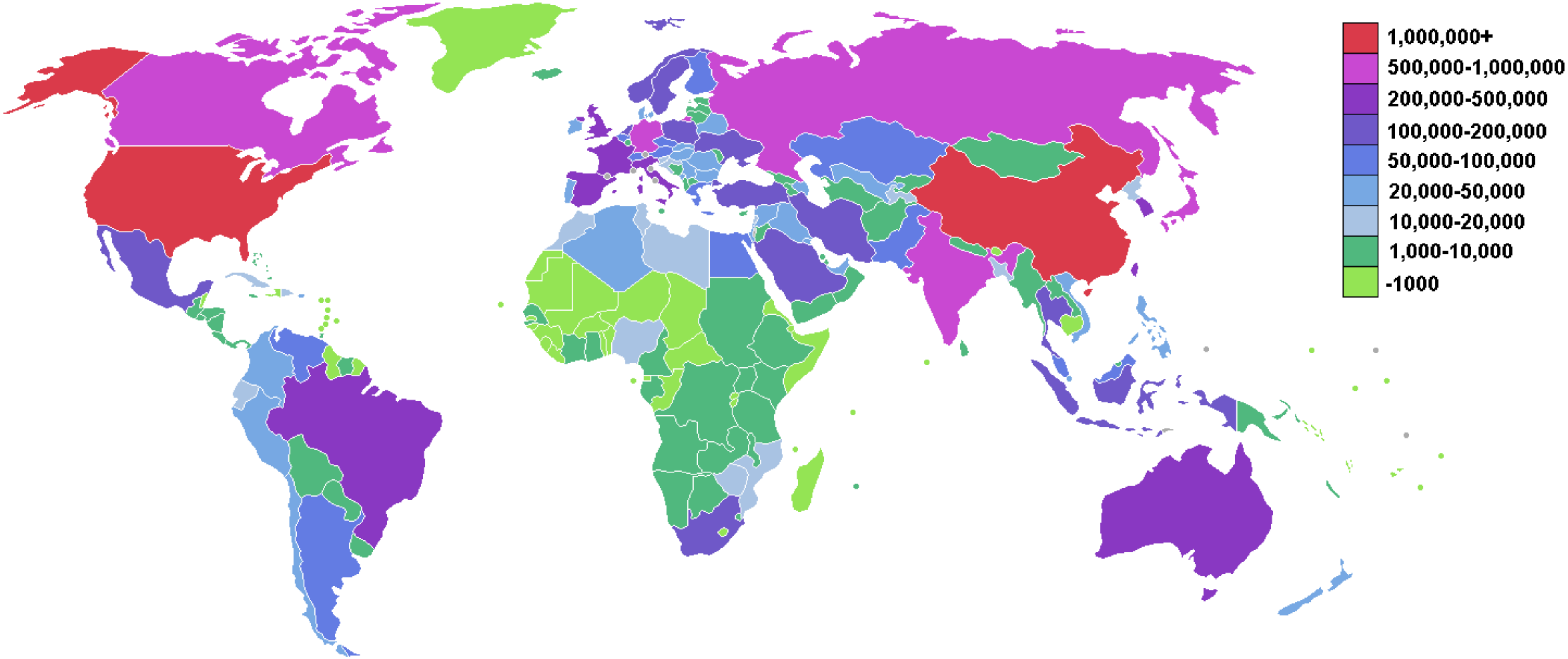
- World Economy Consumed 16.8 terawatts of electricity in 2006
- Required 6.7 billion tons of coal
- Burning coal releases CO_2



sg.wsj.net/public/resources/images/NA-AW591_C…

HTWI
High Tech Workforce Initiative

Who Consumes It?

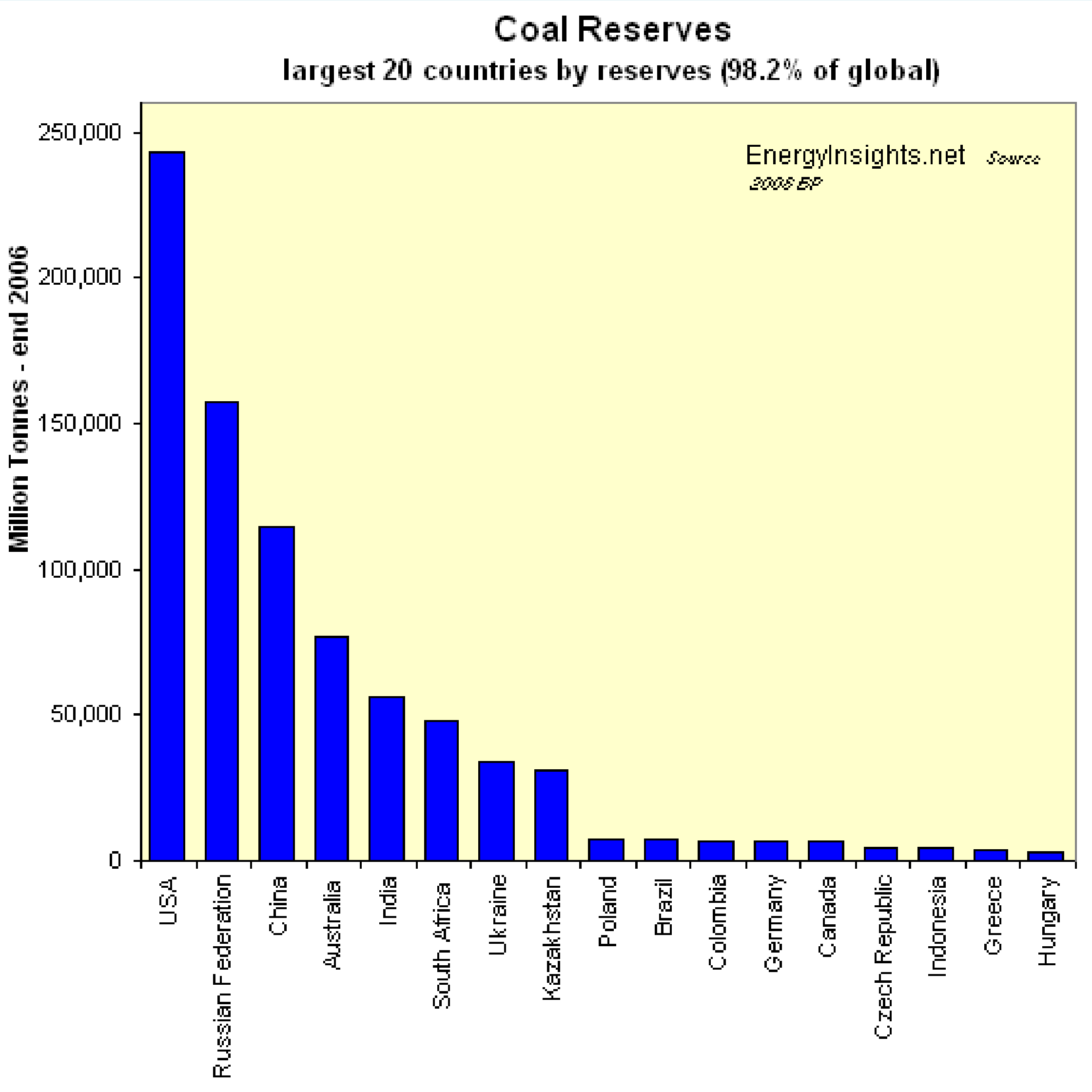


countries.bridgat.com/images/World_Map.gif

HTWI
High Tech Workforce Initiative

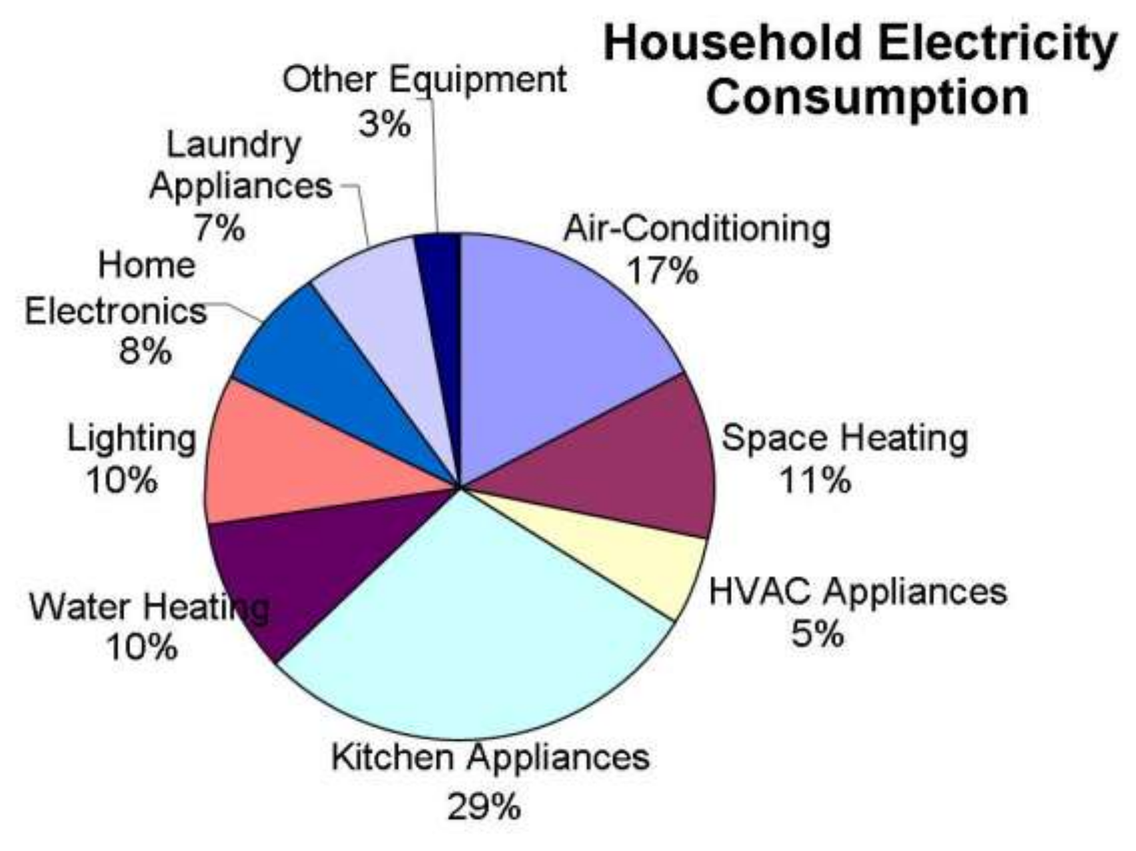
- Recoverable coal reserves in the world:
  1) United States
  2) Russia
  3) China
  4) Australia
  5) India
  6) South Africa

- Each country has the resources to meet electrical needs for many years.



www.energyinsights.net/cgi-script/csArticles/…

What About U. S. Household Consumption?



Household electricity use in the U.S.

HTWI
High Tech Workforce Initiative

What About Household Consumption?

Type of Housing	Kilowatt-hours per year
Single Family Home	7,105
Townhome	4,469
2 – 4 Unit Apartment	3,877
5+ Unit Apartment	3,807
Mobile Home	5,662

California Statewide Residential Appliance Saturation Study, Volume 2, June 2004

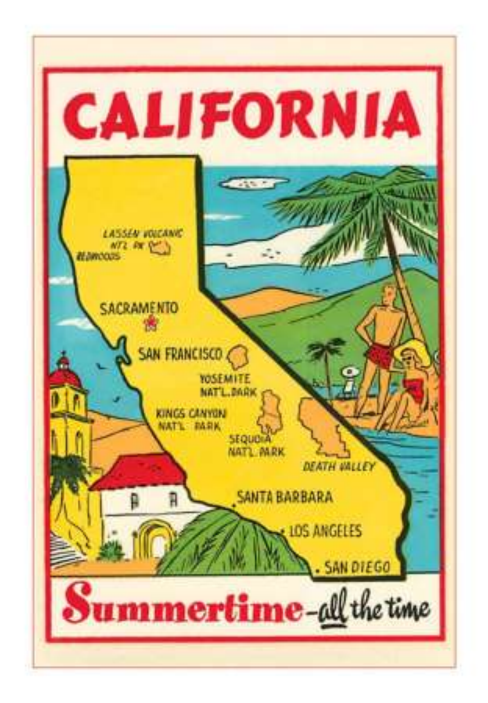
www.callcarolbrady.com/documents/image/Marque...

www.kennycarroll.com/1920Pine-mls.jpg

HTWI
High Tech Workforce Initiative

What About Household Consumption?

- 6,000 kWh per year average in 2004
- kWh per square foot per month
- Laguna Beach = 0.23 kWh/ft^2/month
- 1500 sq. ft home = 4140 kWh per year



fmgpath.com/wp-content/uploads/2009/05/ca-008

HTWI
High Tech Workforce Initiative

Individual Consumption – Video Games

blog.tmcnet.com/blog/tom-keating/images/pong.jpg

www.sciencedaily.com/.../071024145626-large.jpg

HTWI
High Tech Workforce Initiative

Individual Consumption – Video Games

- National Resource Defense Council (NRDC) study on energy use of video game consoles.
- 16 billion kilowatt hours per year
- Annual electricity use for City of San Diego

www.zeldauniverse.net/.../characters/mario.png

blogs.districtadministration.com/photos/uncat...

www.preserveamerica.gov/awards07/hires/source...

HTWI
High Tech Workforce Initiative

Electrical Power Research Institute (EPRI)

Madden NFL 11

Device	Watts / hour
Nintendo Wii	13.7
Sony Playstation 3	84.8
Microsoft Xbox 360	87.9

HTWI
High Tech Workforce Initiative

What’s Your Individual Consumption?

- Determining your individual kWh consumption
- http://michaelbluejay.com/electricity/howmuch.html
- Log usage by item and hours per day or week
- Calculate total

accurateappliancerepair.biz/yahoo_site_admin/…

www.globalnerdy.com/.../05/00s-computers.jpg

www.helenahomegallery.com/wordpress/wp-conten...

new-cell-phone.org/wp-content/uploads/2010/01...

www.moonbattery.com/flat-screen-TV.jpg

www.coffeedome.com/.../2010/01/coffeemaker.jpg

HTWI
High Tech Workforce Initiative

www.apartmenttherapy.com/images/uploads/11-13...

blog.craftzine.com/wind-up-lamp03.jpg

www.markbeam.com/images/spinelamp.jpg

How much electrical power is required to run a 100 watt light bulb for 24 hours a day for a year?

100 watts x 1 kWh/1000 watts x 24 hr/day x 365 days/yr

876 kWh

HTWI
High Tech Workforce Initiative

How much coal would this require?

6,150 kWh/ton

sitemaker.umich.edu/.../files/picture1.jpg

www.celsias.com/.../admin/Coal-Pile-797269.jpg

sitemaker.umich.edu/.../files/picture1.jpg

www.celsias.com/.../admin/Coal-Pile-797269.jpg

How much coal would this require?

6,150 kWh/ton

≈ 40% efficiency

High Tech Workforce Initiative

sitemaker.umich.edu/.../files/picture1.jpg

www.celsias.com/.../admin/Coal-Pile-797269.jpg

How much coal would this require?

6,150 kWh/ton

≈ 40% efficiency

0.40 x 6,150 kWh/ton = 2,460 kWh/ton

HTWI

High Tech Workforce Initiative

How much coal would this require?

6,150 kWh/ton

≈ 40% efficiency

0.40 x 6,150 kWh/ton = 2,460 kWh/ton

876 kWh x 2,460 kWh/ton = 0.357 tons

sitemaker.umich.edu/.../files/picture1.jpg

www.celsias.com/.../admin/Coal-Pile-797269.jpg

HTWI

High Tech Workforce Initiative

sitemaker.umich.edu/.../files/picture1.jpg

www.celsias.com/.../admin/Coal-Pile-797269.jpg

How much coal would this require?

6,150 kWh/ton

≈ 40% efficiency

0.40 x 6,150 kWh/ton = 2,460 kWh/ton

876 kWh x 2,460 kWh/ton = 0.357 tons

Approximately 714 pounds

(0.357 tons x 2000 pounds / ton)

HTWI
High Tech Workforce Initiative

What's 714 Pounds of Coal Look Like?

gasprices-usa.com/coal-train330.jpg

- Coal train car
- Approximately 80 tons of coal (160,000 lbs)

HTWI
High Tech Workforce Initiative

What's 714 Pounds of Coal Look Like?

gasprices-usa.com/coal-train330.jpg

- Coal train car
- Approximately 80 tons of coal (160,000 lbs)

- Basketball Units (BUs)
- 1 basketball = 13.4 lbs coal
- 100 watt lamp = 55 BUs
- 55 basketballs of coal

www.pipersvale.suffolk.sch.uk/.../basketball.jpg

How much CO_2 is produced?

- Simplified Coal Combustion Reaction

$$C(s) + O_2(g) \rightarrow CO_2(g) + \text{heat}$$

- 12 g C reacts with 32 g O_2 producing 44 g CO_2
- Ratio of CO_2 / C = 44 g CO_2 / 12 g C = 3.67 CO_2/C

bluntobject.files.wordpress.com/2010/01/coal_...

HTWI
High Tech Workforce Initiative

How much CO_2 is produced?

www.apartmenttherapy.com/images/uploads/11-13...

- 714 pounds of coal needed
- 2,620 pounds of CO_2 produced
  (714 pounds C x 3.67 CO_2/C)
- Volume CO_2 produced = 23,186 ft^3
  (20.0 ^oC, 1 atm, density 0.113 lbs/ft^3)

HTWI
High Tech Workforce Initiative

How much CO_2 is produced?

www.apartmenttherapy.com/images/uploads/11-13...

- 714 pounds of coal needed
- 2,620 pounds of CO_2 produced
  (714 pounds C x 3.67 CO_2/C)
- Volume CO_2 produced = 23,186 ft^3
  (20.0 ^oC, 1 atm, density 0.113 lbs/ft^3)

- Basketball Units (BUs)
- 1 basketball = 0.260 ft^3
- 100 watt lamp = 23,186 ft^3
- 90,000 basketballs of CO_2

www.pipersvale.suffolk.sch.uk/.../basketball.jpg

HTWI
High Tech Workforce Initiative

90,000 Basketballs?

www.wingweb.co.uk/wingweb/img/500-Air_Force_O...

ryefly.tripod.com/pictures/usair747nose.jpg

- Boeing 747 volume 31,285 ft^3

www.petergreenberg.com/wp-content/uploads/200...

HTWI
High Tech Workforce Initiative

United States Per Capita Electricity Use by Sector: 2005 (11)

Section	Electricity use (kWh / person)
Residential	4,586
Commercial	4,302
Industrial	3,438
Total	12,326

- 12,326 kWh = 5 tons coal = 825 basketballs of coal
- 347,790 ft^3 CO_2 = 1,350,000 basketballs of CO_2
- Fifteen 747 airliners

Survey Question #1

How many hours per week do you and /or the members of your household watch TV?

A. 10 or less hours
B. 10 to 20 hours
C. 20 to 30 hours
D. 30 to 40 hours
E. 40 hours (or more)

Type them in your chat window

Making Electricity and Capturing CO_2

HTWI
High Tech Workforce Initiative

History of Coal

www.jamespreller.com/wp-content/uploads/2009/...

3000 – 4000 years: Bronze Age

www.chekyang.com/musings/wp-content/uploads/2...

1300's Hopi tribes

1306 King Edward I

1700's – Industrial Revolution

leohorowitz.qwriting.org/files/2010/10/indust...

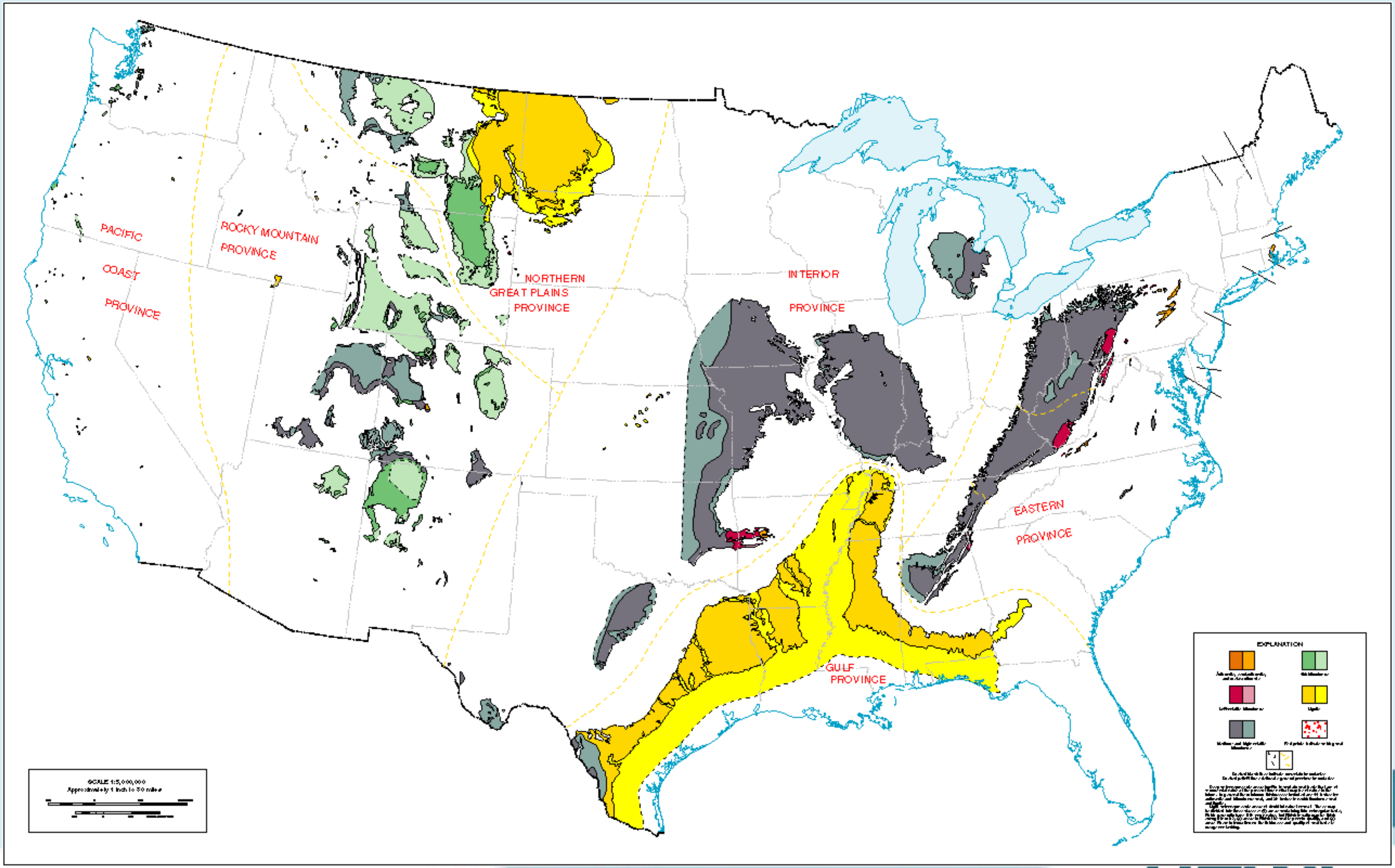
HTWI
High Tech Workforce Initiative

Chemical Changes with Coal Rank

Material	Caron (mass %)	Hydrogen (mass %)	Oxygen (mass %)
Wood (cellulose)	44	6	50
Peat	59	6	35
Lignite Coal	71	5	24
Subbituminous Coal	74	5	21
Bituminous Coal	84	5	11
Anthracite	94	3	3
Graphite (not a coal)	100	0	0

- Plant debris evolves to coal
- Mass percent carbon = higher coal ranking
- Higher coal ranking = higher caloric value
- Bituminous coal – most abundant rank

Coal in the United States



HTWI
High Tech Workforce Initiative

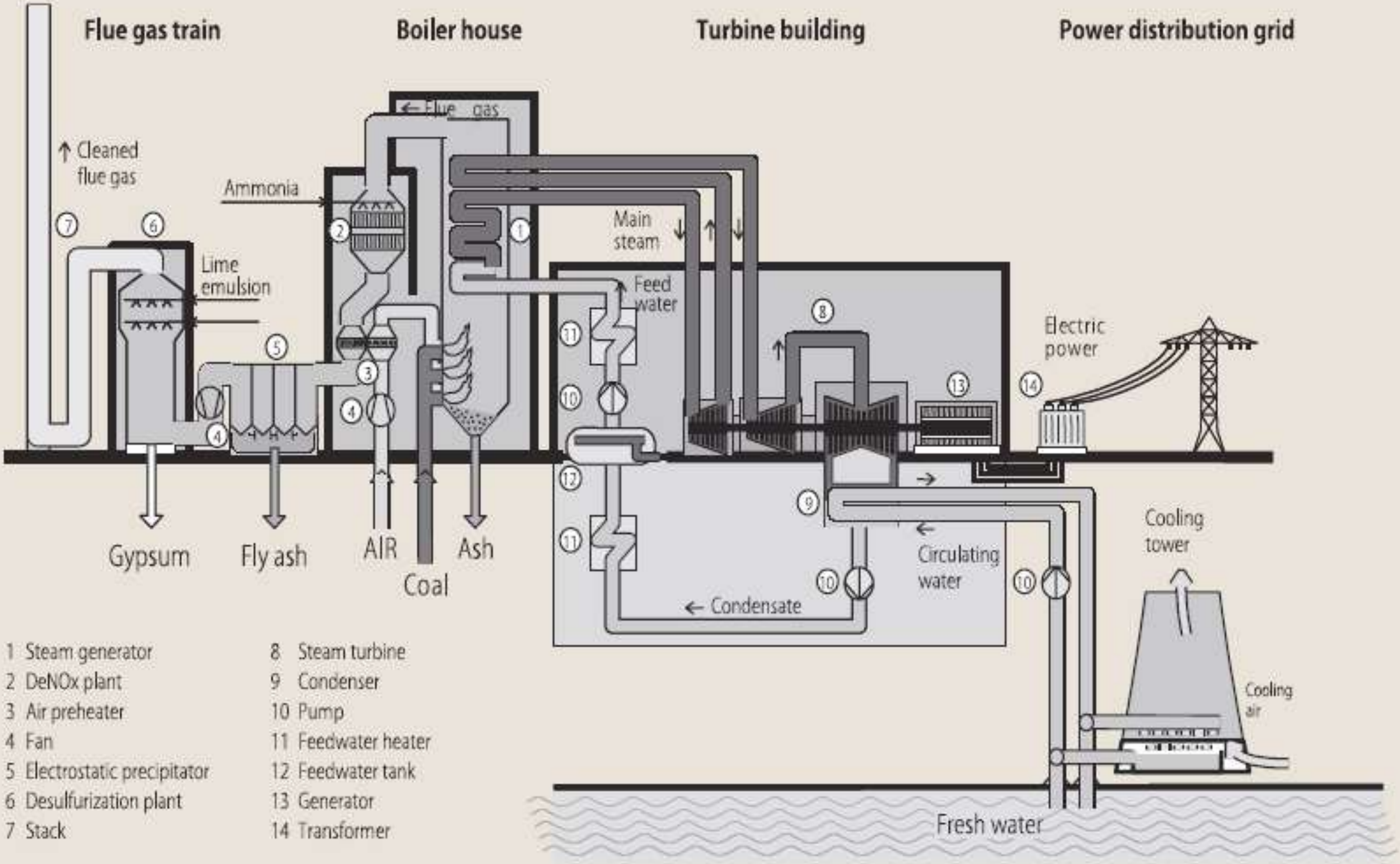
Pulverized Coal (PC) Power Plants

- Traditional and most abundant (5,400 plants)
- Older technology
- Efficiency ≈ 34%
- Flue gas 15 – 20% CO_2

HTWI
High Tech Workforce Initiative

Pulverized Coal (PC) Power Plants

- Traditional and most abundant (5,400 plants)
- Older technology
- Efficiency ≈ 34%
- Flue gas 15 – 20% CO_2
- Three main areas:
  - Boiler block = coal is burned to generate steam
  - Generator block = steam turbine generates electricity
  - Flue gas clean up = removes particulates and pollutants



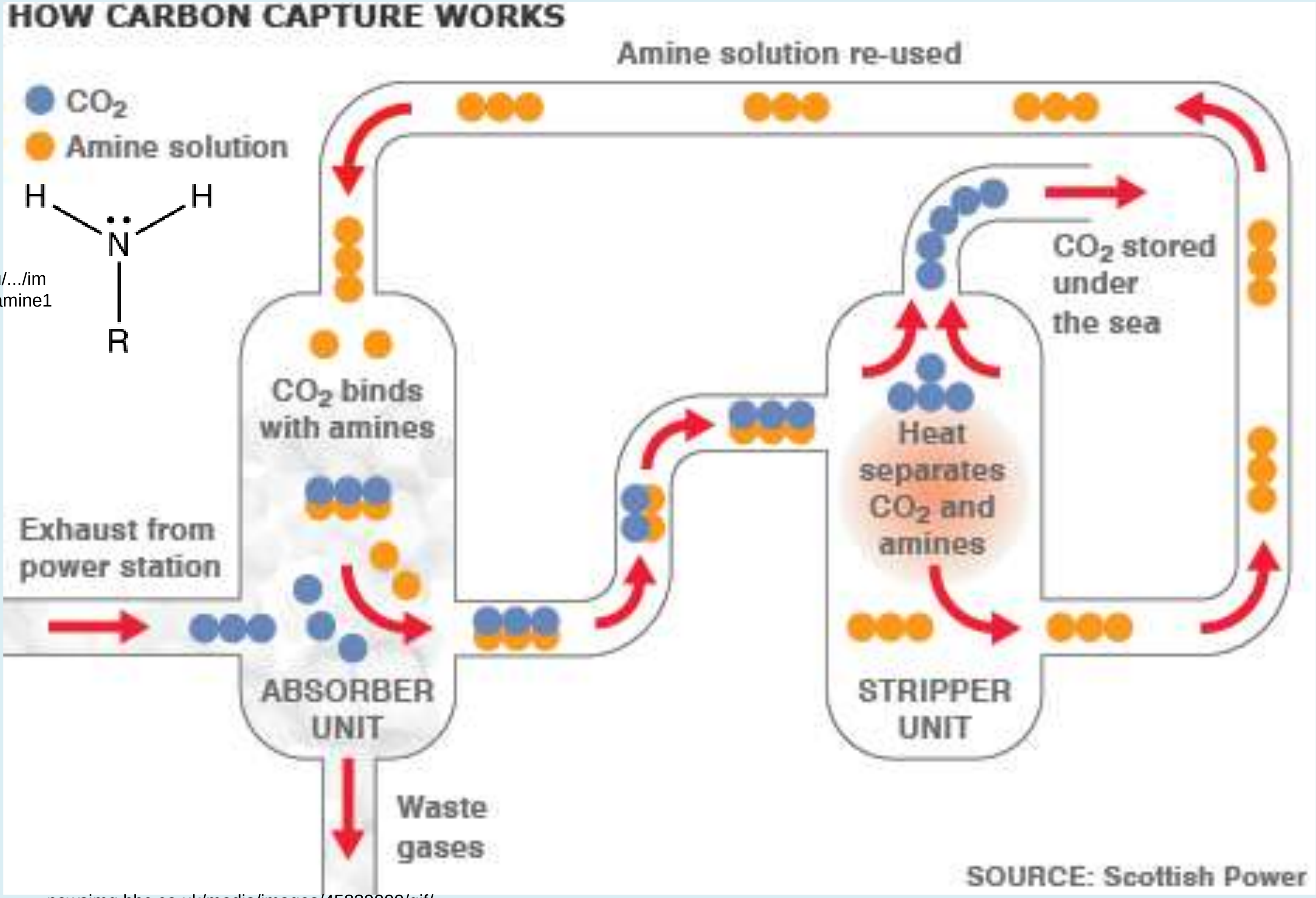
Courtesy ASME.

Schematic of Low-Emissions, Pulverized Coal Power Plant. (8)

How Does Power Plant Work?

- Video explaining the basics of how a coal fired power plant works.
- How a coal fired power plant works.

- http://www.youtube.com/watch?v=SeXG8K5_UvU&feature=related



science.uvu.edu/.../images/P/primaryamine1.png

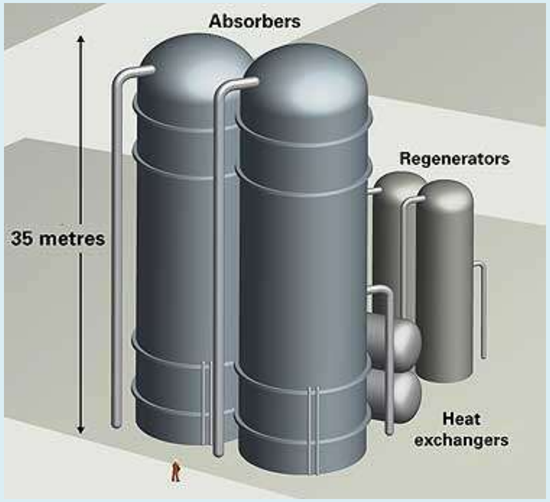
newsimg.bbc.co.uk/media/images/45839000/gif/_...

$$2RNH_2(aq) + CO_2(g) + H_2O(l) \rightarrow (RNH_3)_2CO_2(aq) \rightarrow 2RNH_3^+(aq) + HCO_3^-(aq)$$

HTWI
High Tech Workforce Initiative

Post Combustion (PC) CO_2 Capture & Parasitic Load

Component	Without CO_2 cap (kg/hr)	With CO_2 capture (kg/hr)
Coal feed	208,000	284,000
Feed air consumed	2,111,000	2,890,000
CO_2 emitted to atmosphere	466,000	63,600
SO_2 emitted to atmosphere	136	1.8
NO_x emitted to atmosphere	114	78.1
Electric power	500 mW	500 MW
CO_2 capture	None	130 MW
CO_2 compression	None	70 MW
Cost of Electricity	4.64¢ per kWh	8.24¢ per kWh



iongenericarticle.do?categoryId=9023211&contentId=7043026

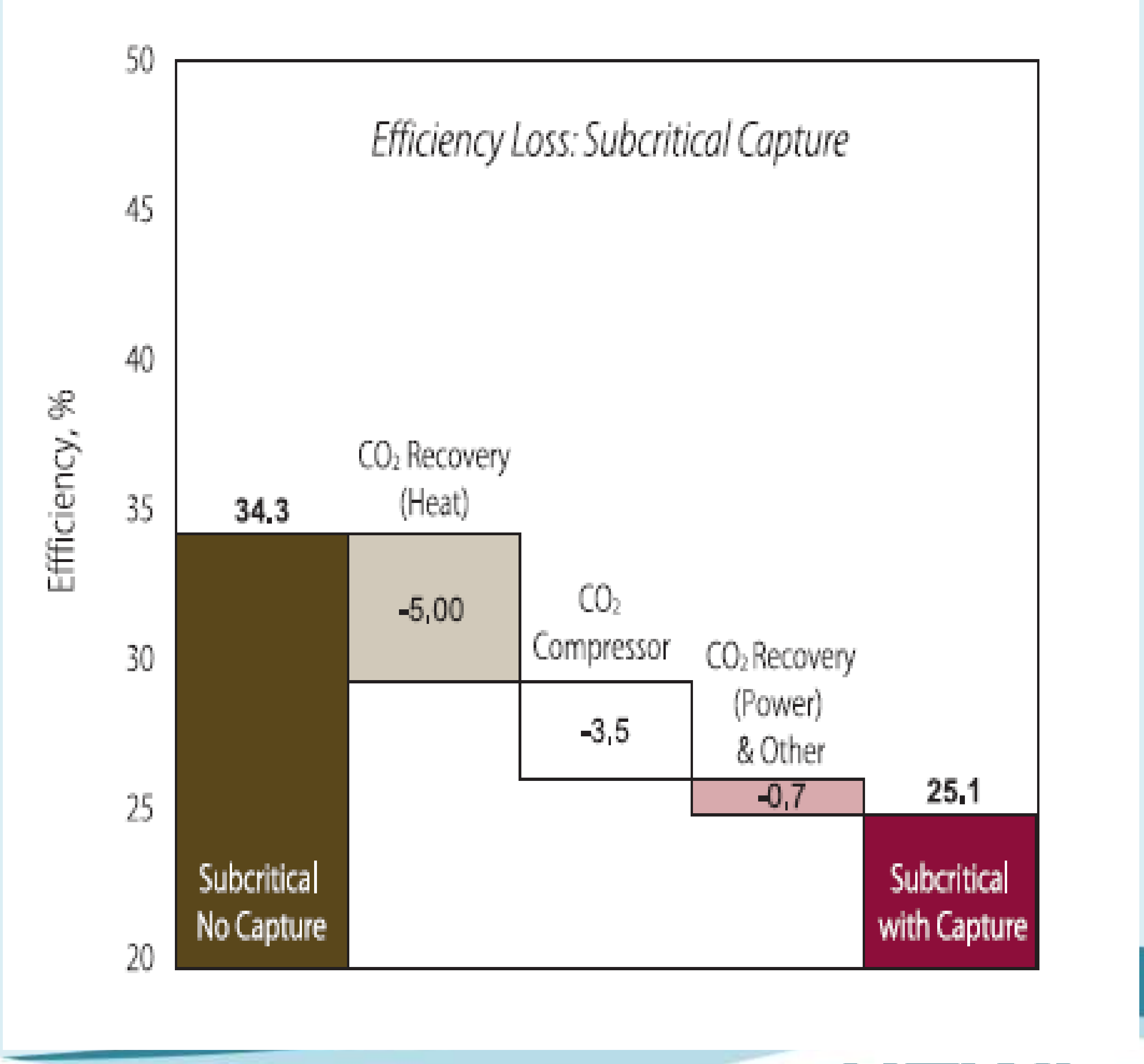
www.amecparagon.com/images/clip_image002_0001.jpg

•The Future of Coal, Figure A – 3.B.2 & 6, pages 116 & 118.

HTWI
High Tech Workforce Initiative

Parasitic Energy Requirements – PC with CO_2 Capture

Parasitic Loss = 9.2%



HTWI
High Tech Workforce Initiative

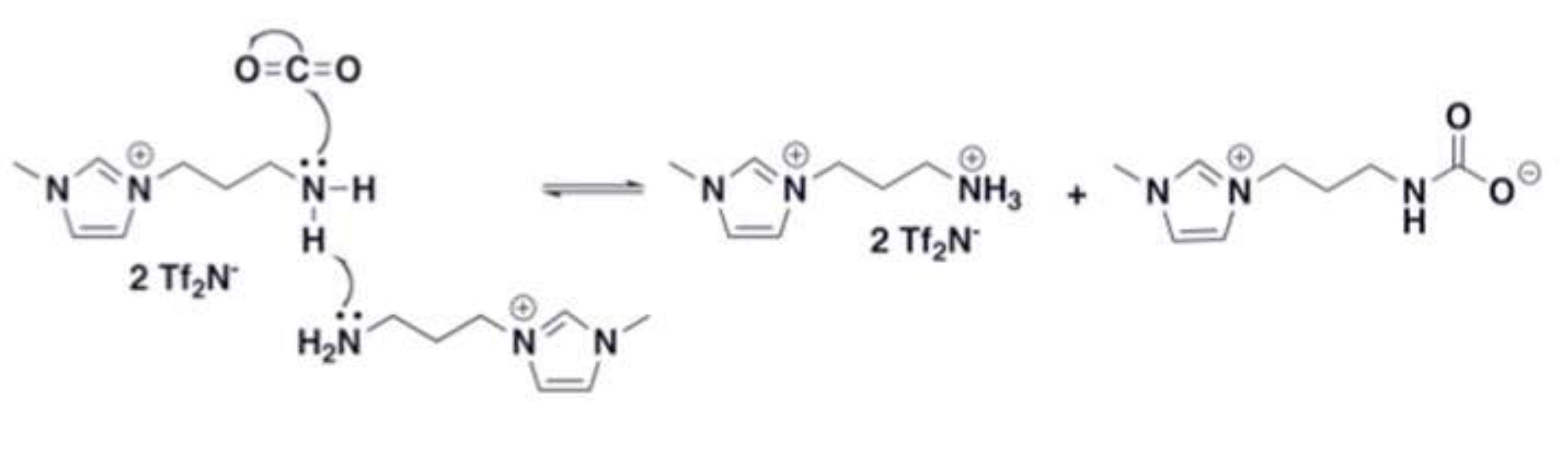
Paradigm Changing Emerging Technologies

Room Temperature Ionic Liquids (RTILs)

- Nonvolatile solvents – negligible volatility
- High intrinsic CO_2 soluble at low pressure and room temperature
- Low solubility for O_2 and N_2
- High diversity of compounds to allow for custom “design” for fine tuning properties.
- When incorporated into a membrane show selectively high permeability to CO_2
- Do not require water to function
- Better performance than amine sorbents (MEAs)

These technologies lower parasitic load for the capture of CO_2.

Room Temperature Ionic Liquids (RTILs)



Amine–tethered Cations (TSILs) from "Development of New Post-Combustion Carbin Dioxide Capture Solvents: Are Ionic Liquids the Answer?

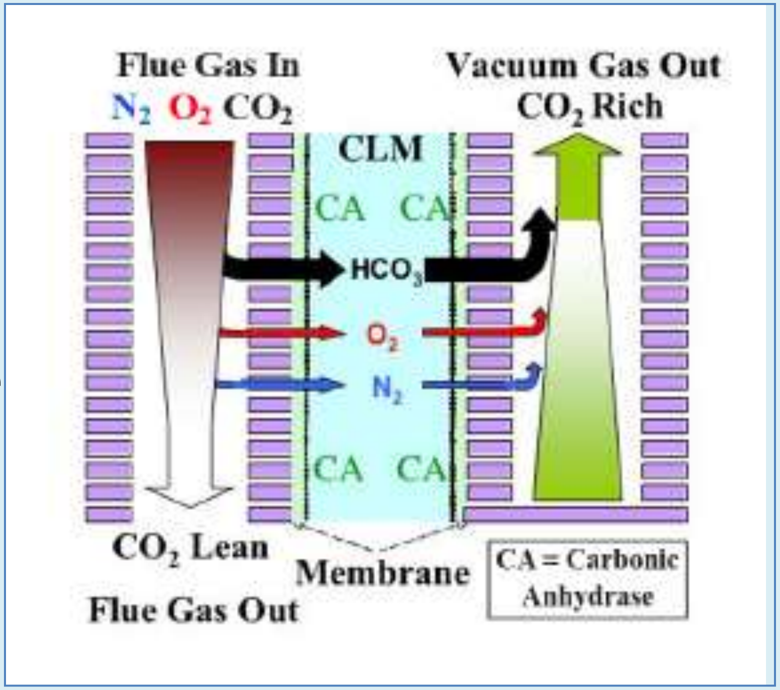
Edward Maginn, University of Notre Dame (4/7/2008)

HTWI
High Tech Workforce Initiative

Paradigm Changing Emerging Technologies

Organic Membranes

- Carbozyme Thermoplastic Technology's (biomimetic technology)
- Fast catalyst – carbonic anhydrase
- A high efficiency mass transfer hollow fiber design
- Low energy requirement – does not require high value steam (low pressure and temperature)
- Differentiable permeable to HCO_3^-
- Slightly permeable to O_2 & N_2 but move slowly through the membrane



images-en.busytrade.com/16426300/Ceramic-Mem...

HTWI
High Tech Workforce Initiative

Paradigm Changing Emerging Technologies

- Ceramic Membranes
  - made from inorganic materials (such as alumina, titania, zirconia oxides or some glassy materials)
  - used in separations in aggressive media (acids, strong solvents)
  - have excellent thermal stability which make them usable in high temperature

images-en.busytrade.com/126426300/Ceramic-Mem...

Post Combustion (PC) CO_2 Capture

Pros:

- Feasible retro-fit
- Existing Technology
- Currently in use in other industries
  - Soft drink
  - Natural gas

Cons:

- Parasitic Load
  - High running costs
  - Degrading solvents
- Limited large scale operating experience

Pre Combustion - IGCC

- Integrated Gasification Combined Cycle (IGCC)

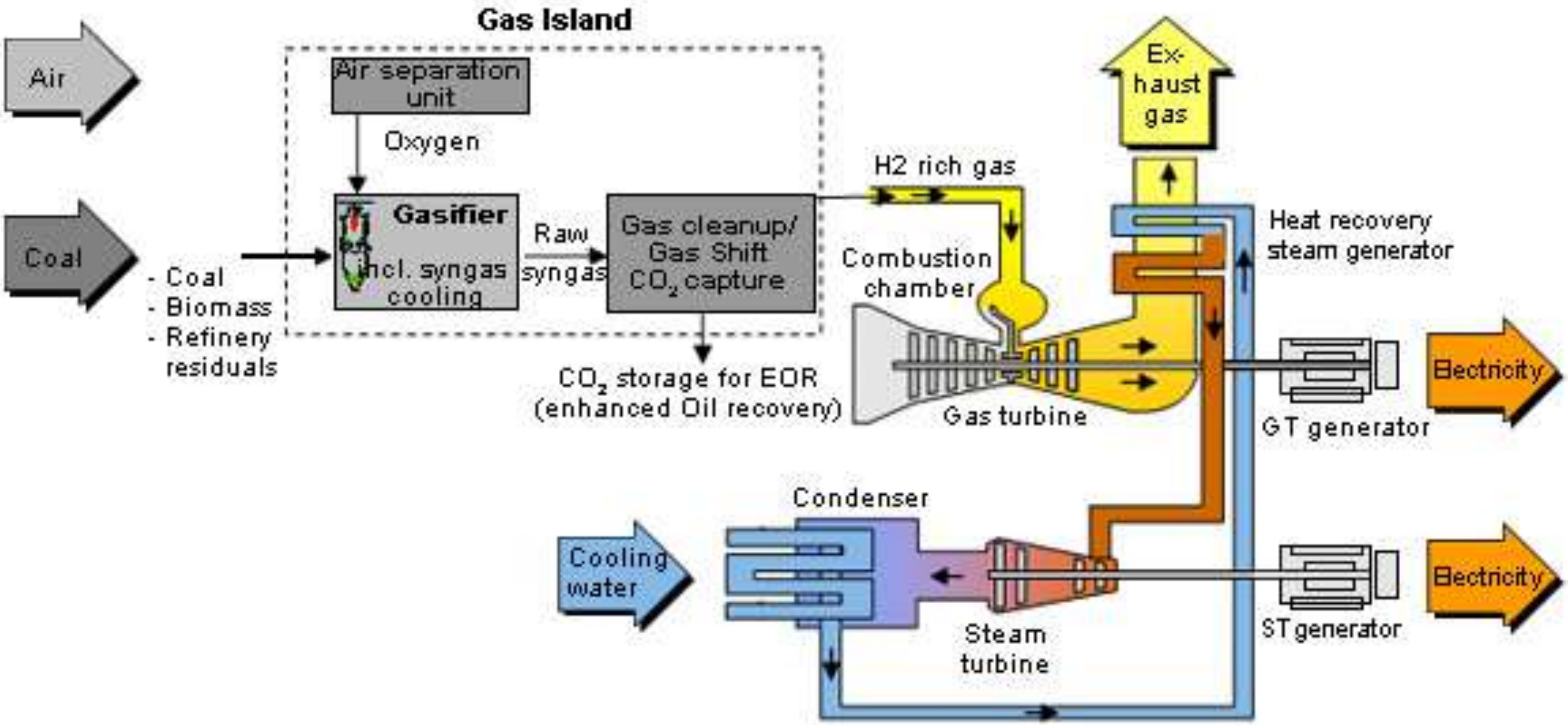
$$C_{(s)} + 2H_2O_{(g)} \rightarrow CO_{2(g)} + 2H_{2(g)}$$

$$C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$$

- Separation of CO_2 gases – easier
  - high concentration of CO_2 (40%)
  - high temperatures (400 ^{o}C).

HTWI
High Tech Workforce Initiative

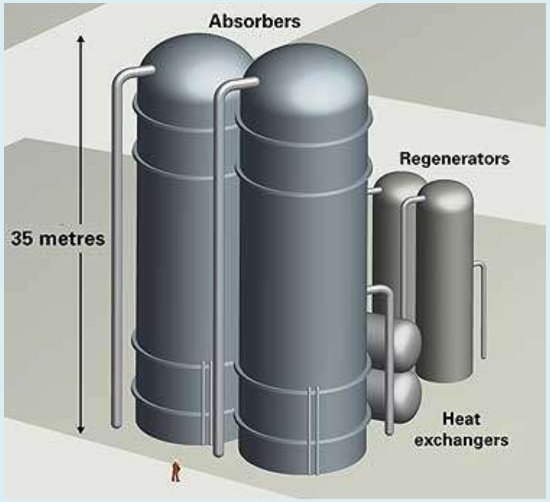
IGCC – Integrated Gasification Combined Cycle



cn.siemens.com/.../IGCC_schematic_578px.jpg

Pre Combustion (IGCC) CO_2 Capture

- Syngas (H_2 + CO) burned to make steam & electricity
- High pressure system makes this easier
  - Exhaust gas 90 – 95% CO_2
  - Henry's Law (pressure & solubility)
- High pressure absorber
- Low pressure regenerator



http://www.bp.com/sectiongenericarticle.do?categoryId=9023211&contentId=7043026

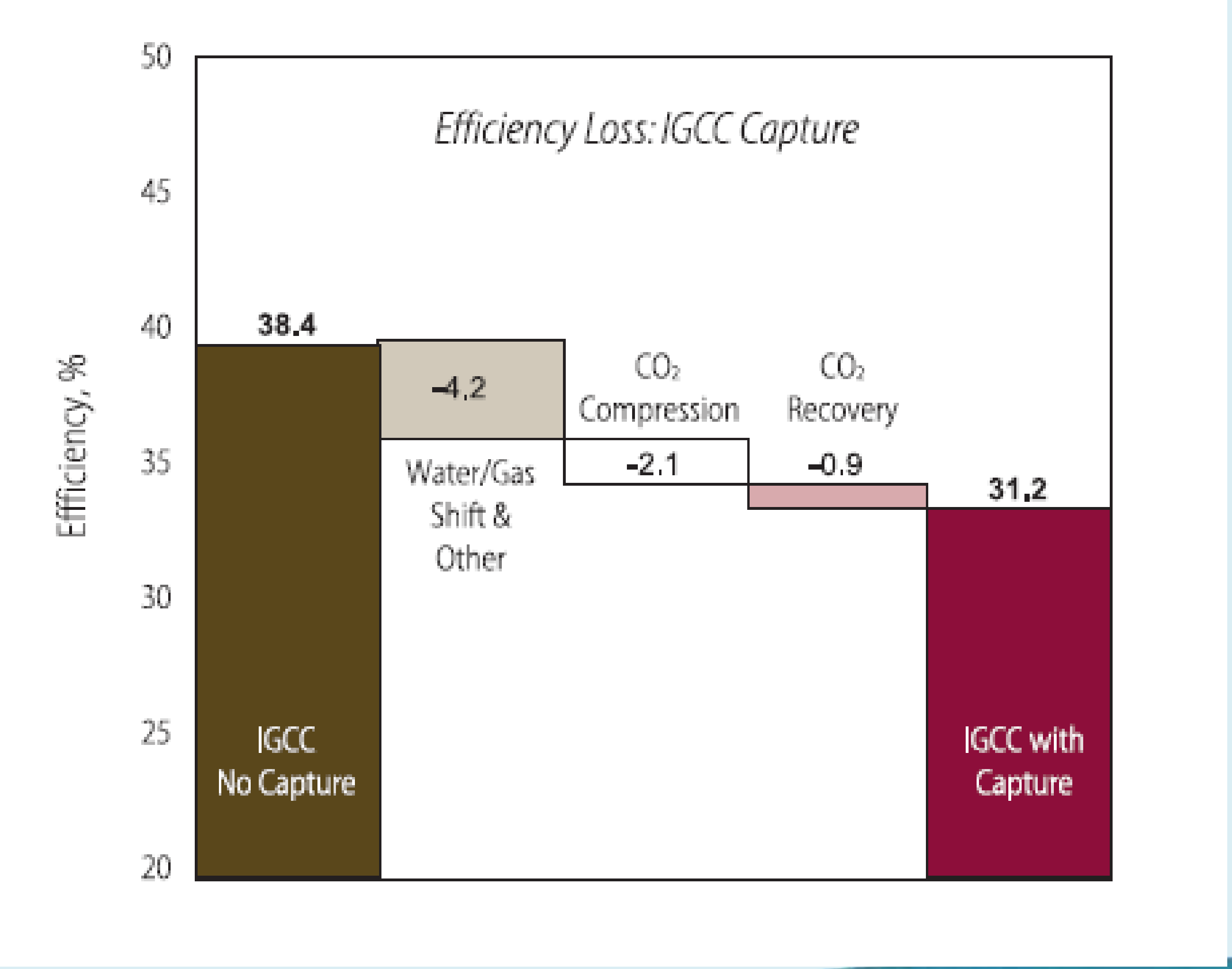
HTWI
High Tech Workforce Initiative

View of IGCC Pilot Power Plant

www.hitachi.com/.../images/img_coal/coal_16.jpg

Parasitic Energy Requirements – IGCC with CO_2 Capture

Parasitic Loss = 7.2%



Pre Combustion (IGCC) CO_2 Capture

Pros:

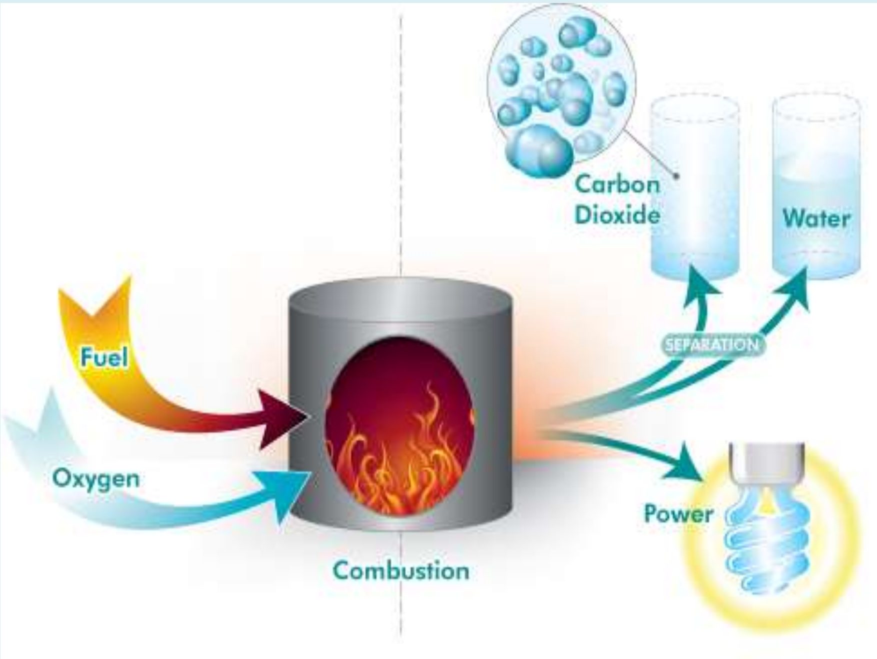
- Proven industrial scale
  - Oil refineries
- 90 – 95% CO_2 captured
- Applies to natural gas and coal fired IGCC power plants
- Lowest technological risk
- Produces H_2 & liquid fuels

Cons:

- Requires chemical plant in front of gas turbine
- High investment costs of building new plant
- Efficiency of H_2 burning turbines lower than conventional turbines

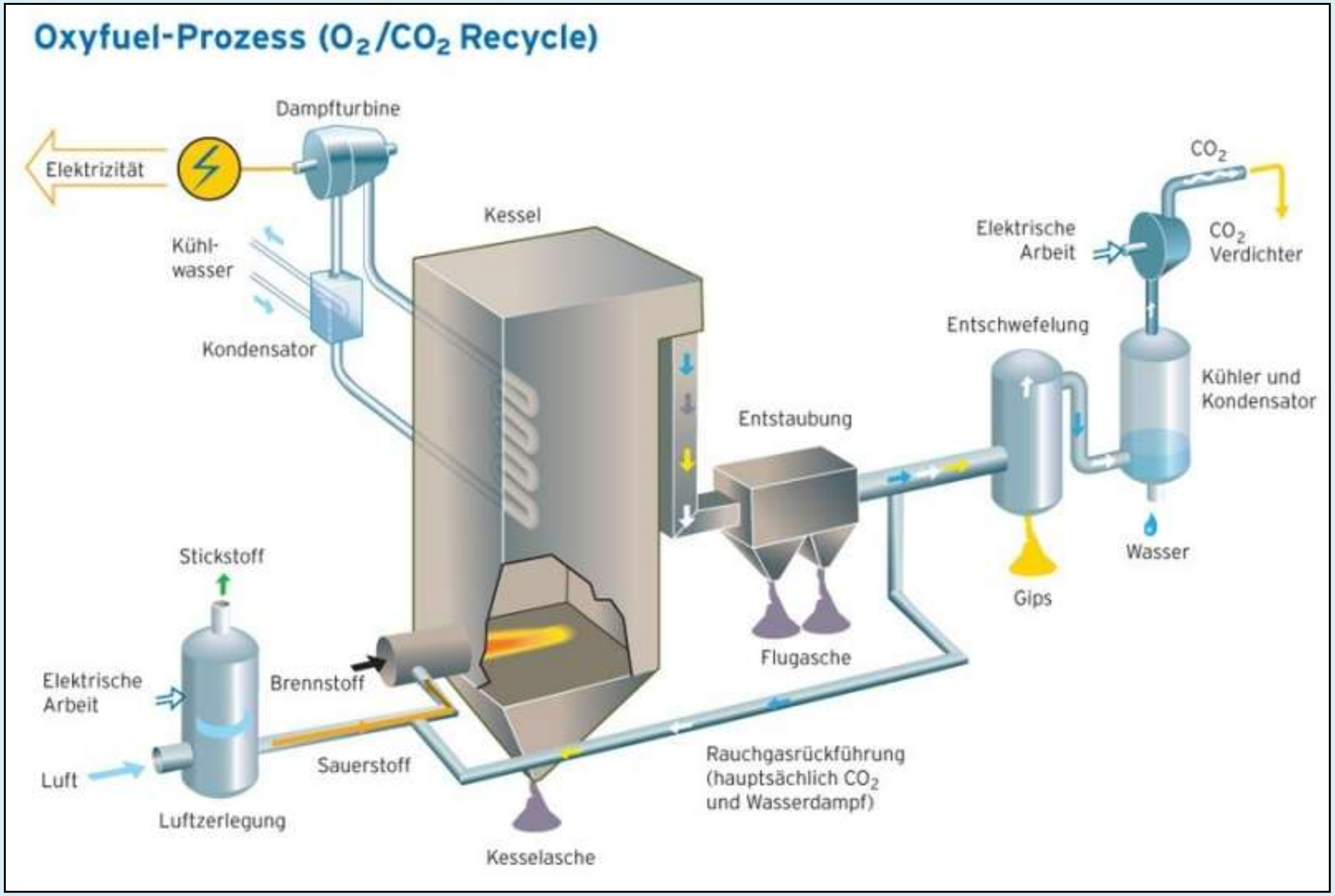
Oxy-Combustion

- Burning coal in pure oxygen
- Exhaust stream CO_2 and H_2O
- Air Separation Unit (ASU)
  - Cryogenic process purifies O_2 from atmospheric air
  - Takes 15% of electricity plant generates to run



HTWI
High Tech Workforce Initiative

Oxy-Combustion



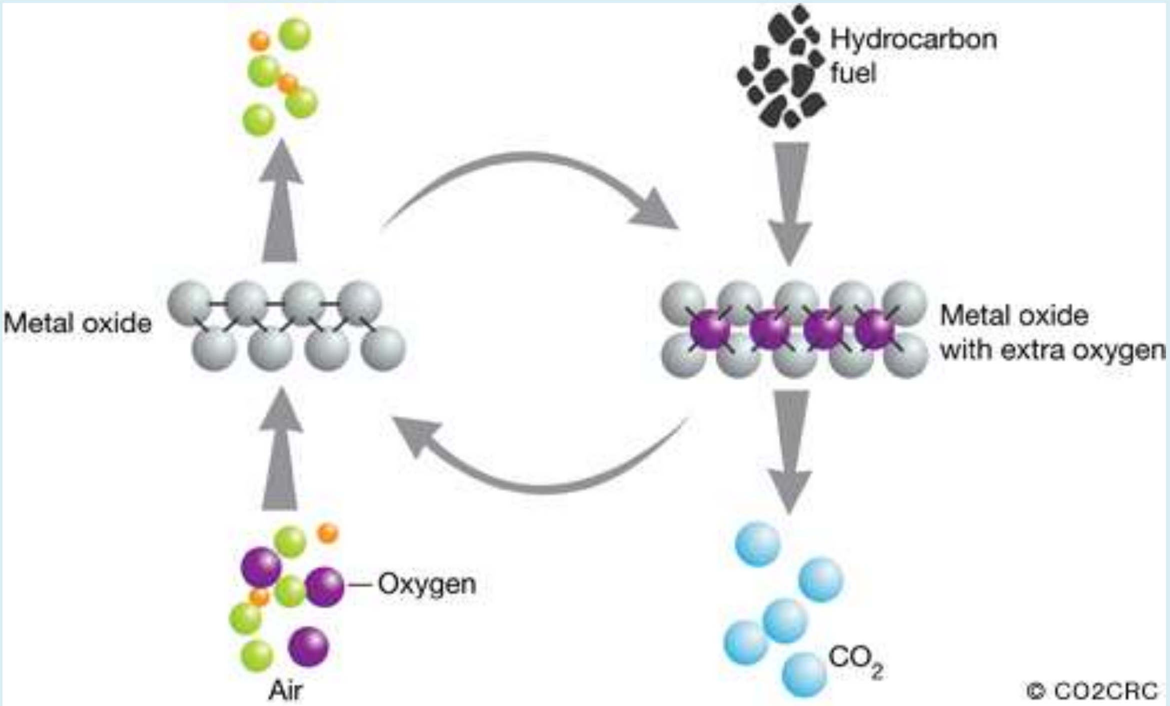
Pure O_2 from ASU used in coal combustion

Easy to separate CO_2 and H_2O based on physical properties (BP)

www.engineerlive.com/.../large_1332428tec_l.jpg

HTWI
High Tech Workforce Initiative

Chemical Looping Combustion (CLC)



www.co2crc.com.au/.../chemical_looping.jpg

$2Ni_{(s)} + O_2(g) \rightarrow 2\ NiO_{(s)}$

$\underline{C(s) + 2NiO(s) \rightarrow CO_2(s) + 2Ni(s) + Heat}$

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} + Heat$

HTWI
High Tech Workforce Initiative

Oxy Combustion CO_2 "Capture"

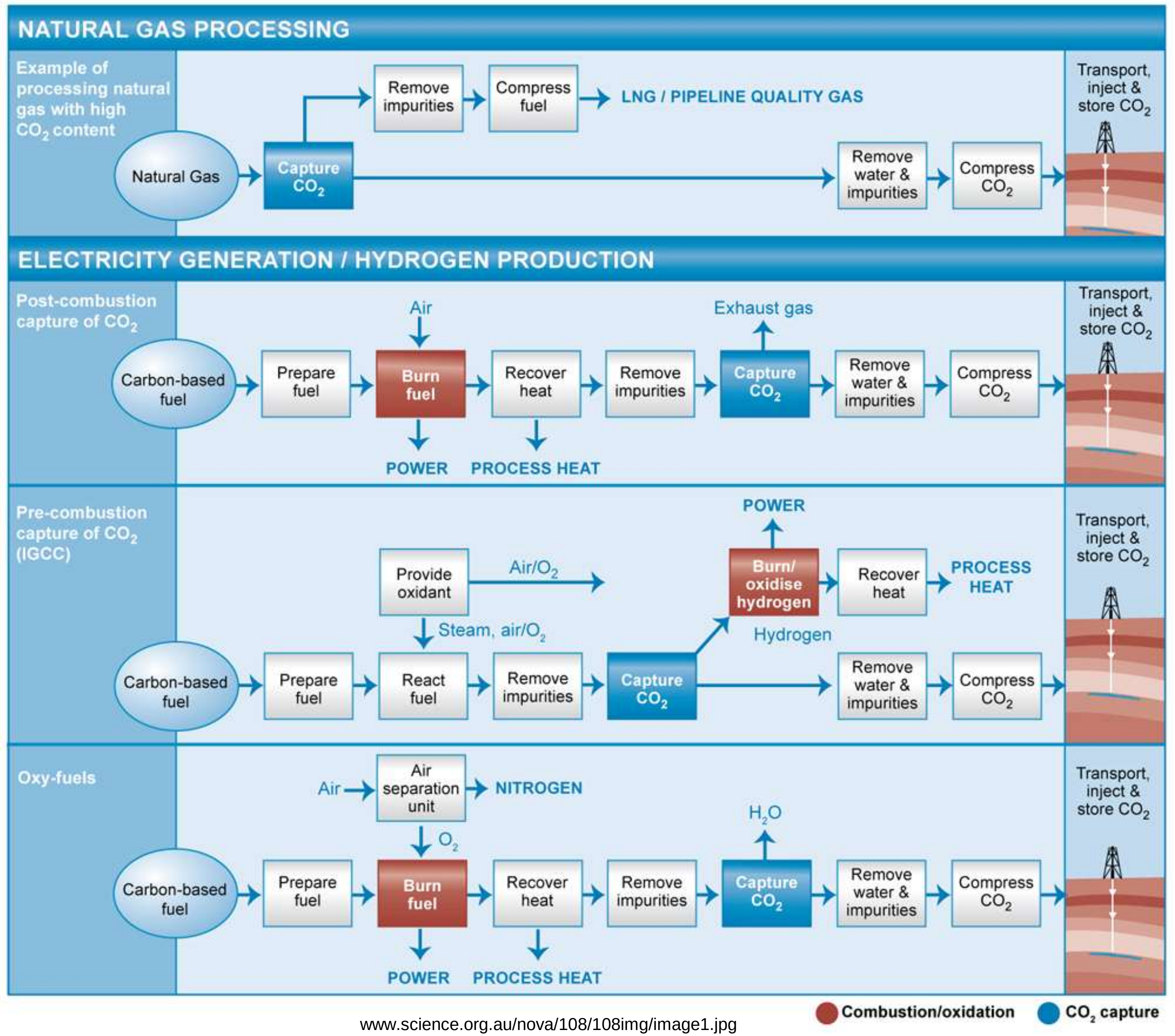
Pros:

- Potential for 100% capture
- Few other harmful emissions
  - N_2 removed in ASU, no nitrogen oxides (NO_x)
- Retrofits possible on existing coal power plants

Cons:

- High energy penalty for cryogenic ASU
- Parasitic loss 8.3%
- Only one demonstration plant (Vallenfall)

Summary of Electricity Production & CO_2 Capture



www.science.org.au/nova/108/108img/image1.jpg

Summary of Electricity Production & CO_2 Capture

Performance	PC w/o CO_2 capture	PC with CO_2 capture	IGCC W/O CO_2 capture	IGCC with CO_2 capture	OXY with CO_2 capture
Efficiency	38.5%	29.3%	38.4%	31.2%	30.6%
Coal feed (kg/h)	184,894	242,950	185,376	228,155	232,628
CO_2 emitted (kg/h)	414,903	54,518	415,983	51,198	52,202
CO_2 captured at 90% (kg/h)	0	490,662	0	460,782	469,817
CO_2 emitted (g/kWh)	830	109	832	102	104
Cost of electric					
COE (¢/kWh)	4.78	7.69	5.13	6.52	6.98

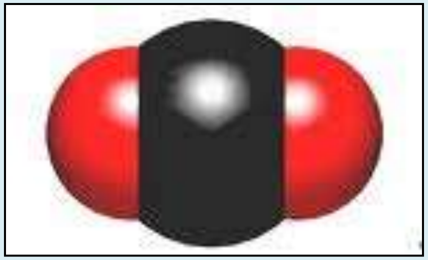
Survey Question #2

Which type of power plant should we build as we replace our aging coal fired power plants over the next 30 years?

A. Coal Fired Power Plant
B. Coal fired power plant with CO_2 capture
C. IGCC Power Plant
D. IGCC Power Plant with CO_2 capture
E. Oxy-Combustion Power plant wit CO_2 capture.

Type them in your chat window

Managing CO_2



- Carbon as a Commodity
- Carbon Sequestration
- Recycling CO_2 into commercial products

www.scienceclarified.com/.../uesc_02_img0110.jpg

www.parcbench.com/.../12/CO2_zoom_RTR1QBSN.jpg

CO_2 as a Commodity

- Production of Urea for fertilizer

3.bp.blogspot.com/.../5HRLv4cIqxY/s1600/pic3.jpg

www.orau.org/.../fertilizer.jpg

- Refrigeration Systems – safer than CFC’s

www.underlevel.net/.../03/moving_a_refrig_2.jpg

cambridgeenergyalliance.org/wp-content/upload

- Inert Agent for Food Packaging

www.daelimcorp.co.kr/.../sp_chem/img_photo34.jpg

- Carbonated Beverages

www.howtoremedyheartburn.com/.../carbdrinks.jpg

HTWI
High Tech Workforce Initiative

CO_2 as a Commodity

4.bp.blogspot.com/.../alam-fire+extinguisher.jpg

www.225steel.com/fabrication-images/ist2_3991...

www.agricultureinformation.com/mag/wp-content...

www.coarsebubblediffuser.com/images/flexcap-1...

- Welding Systems
- Fire Extinguishers
- Water treatment processes
- Horticulture

HTWI
High Tech Workforce Initiative

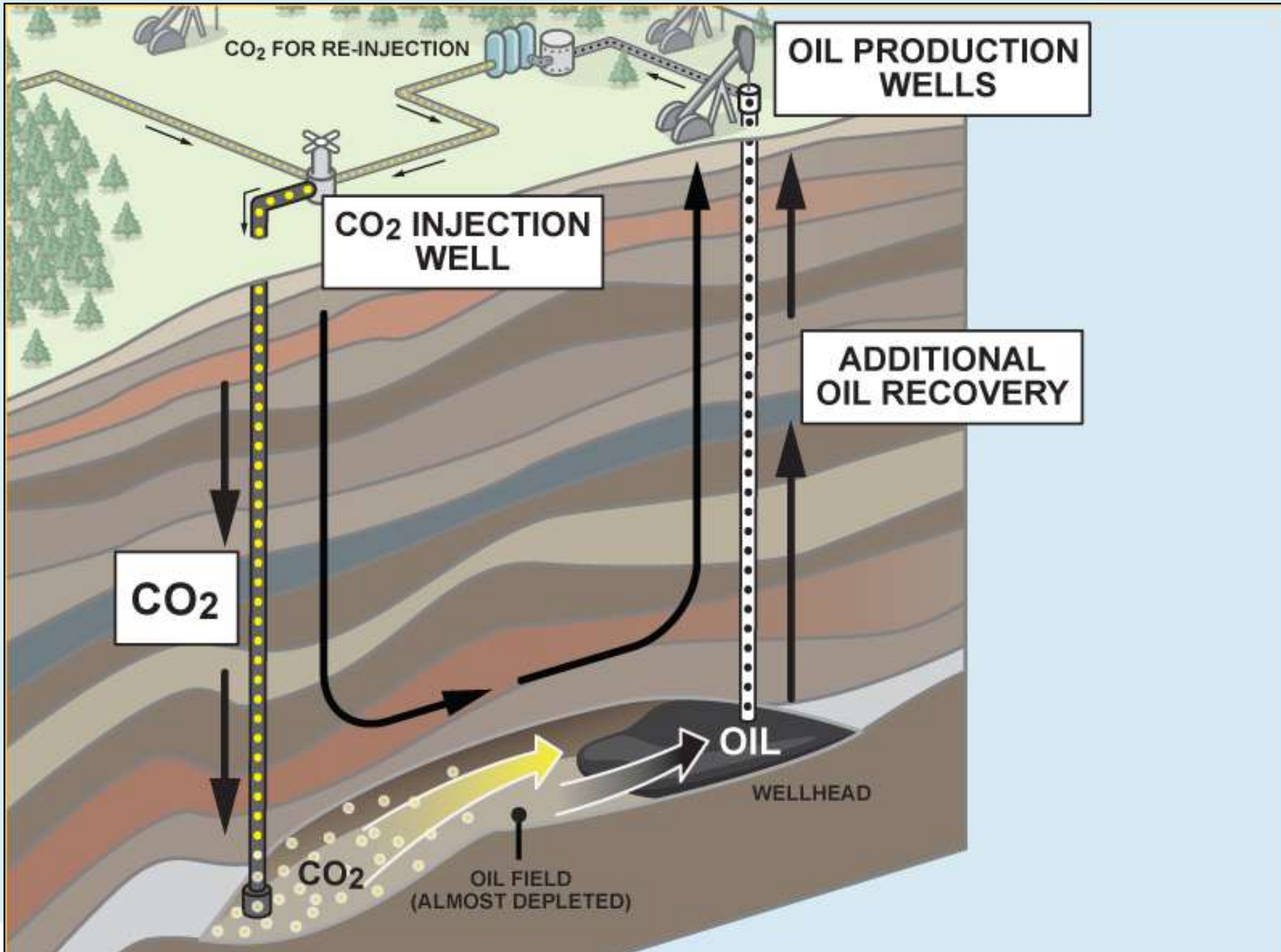
CO_2 as a Commodity

- Precipitated $CaCO_3$ for paper industry

img.alibaba.com/img/imagerepos/cn/22/cn220037...

www.fmcsgvs.com/images/pprolls_01.jpg

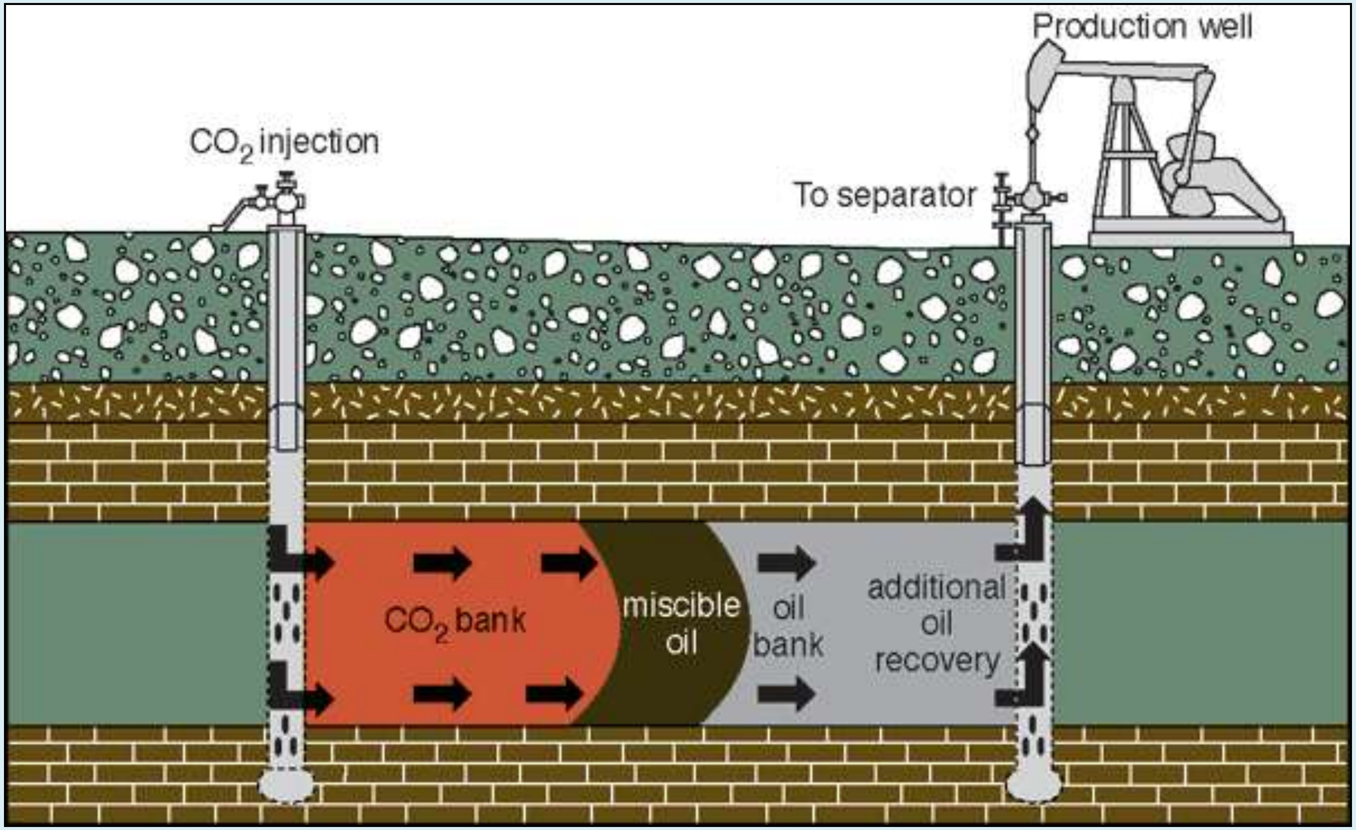
CO_2 as a Commodity – Enhanced Oil Recovery



coaltransition.org

HTWI
High Tech Workforce Initiative

Enhanced Oil Recover (EOR)



http://www.kgs.ku.edu/Publications/PIC/pic27.html

CO_2 used as a solvent to increase oil field production.

HTWI
High Tech Workforce Initiative

petrolog.typepad.com/photos/blog_illustration...

1.2 billion cubic feet CO_2 per day transferred from Southern Colorado CO_2 domes to West Texas Permian oil fields.

25% of today's oil production generated by EOR with CO_2.

HTWI
High Tech Workforce Initiative

EOR Projects

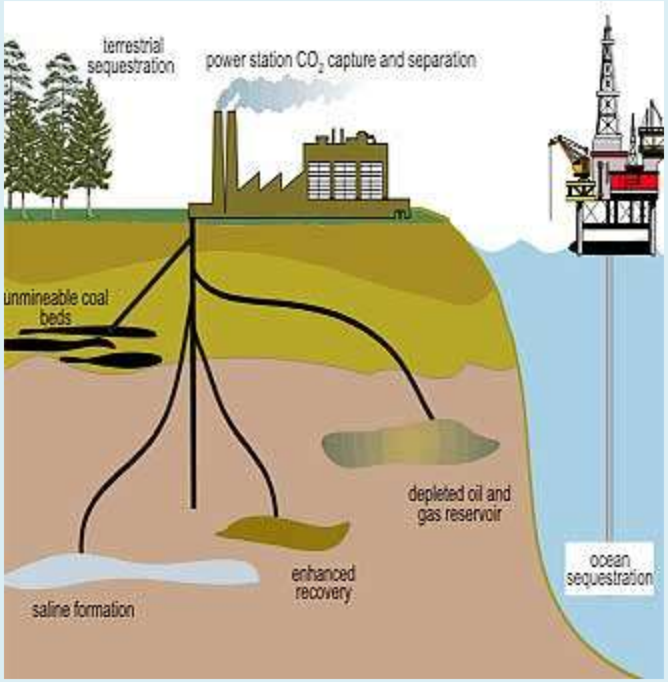
- Occidental Petroleum – 13.5 million tons of CO_2 per year plant in West Texas ($1.1 billion)
  - World's largest user of EOR
- St. John's CO_2 Dome – in eastern Arizona and Western New Mexico border.
  - 5 trillion cubic feet CO_2
  - 30 billion cubic feet He
  - 350 mile pipeline to pump 500 million cubic feet / day to West Texas Permian oil fields.

HTWI
High Tech Workforce Initiative

CO_2 Sequestration

The process of removing carbon from the atmosphere and depositing it in a reservoir.

- Biological
- Ocean
- Geological



carboncycle.biz

Biological Sequestration

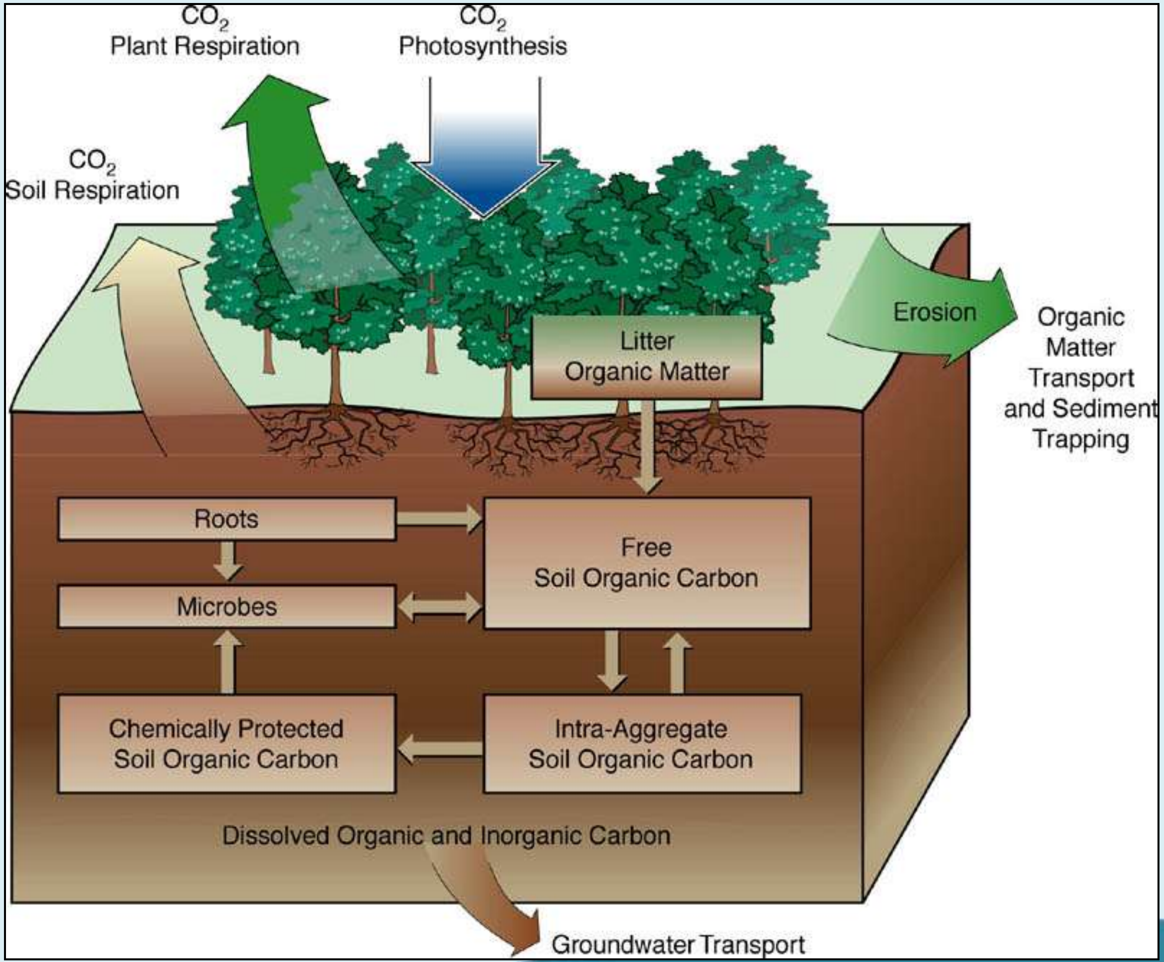
- Managing land in ways which enhance the natural absorption of CO_2 by vegetation and soil.
- Ratio of soil carbon to carbon in vegetation varies depending on the type of ecosystem
  - Tropical rain forest (1/1)
  - Boreal forest (5/1)
  - Wetlands (15/1)
  - Grasslands (33/1)
  - Croplands (43/1)

epa.state.oh.us

HTWI
High Tech Workforce Initiative

Biological Sequestration

- Four forest components:
  - Soil (59%)
  - Trees (31%)
  - Forest floor or litter (9%)
  - low growing vegetation (1%)



tececo.com

Biological Sequestration

northcoastirwmp.net

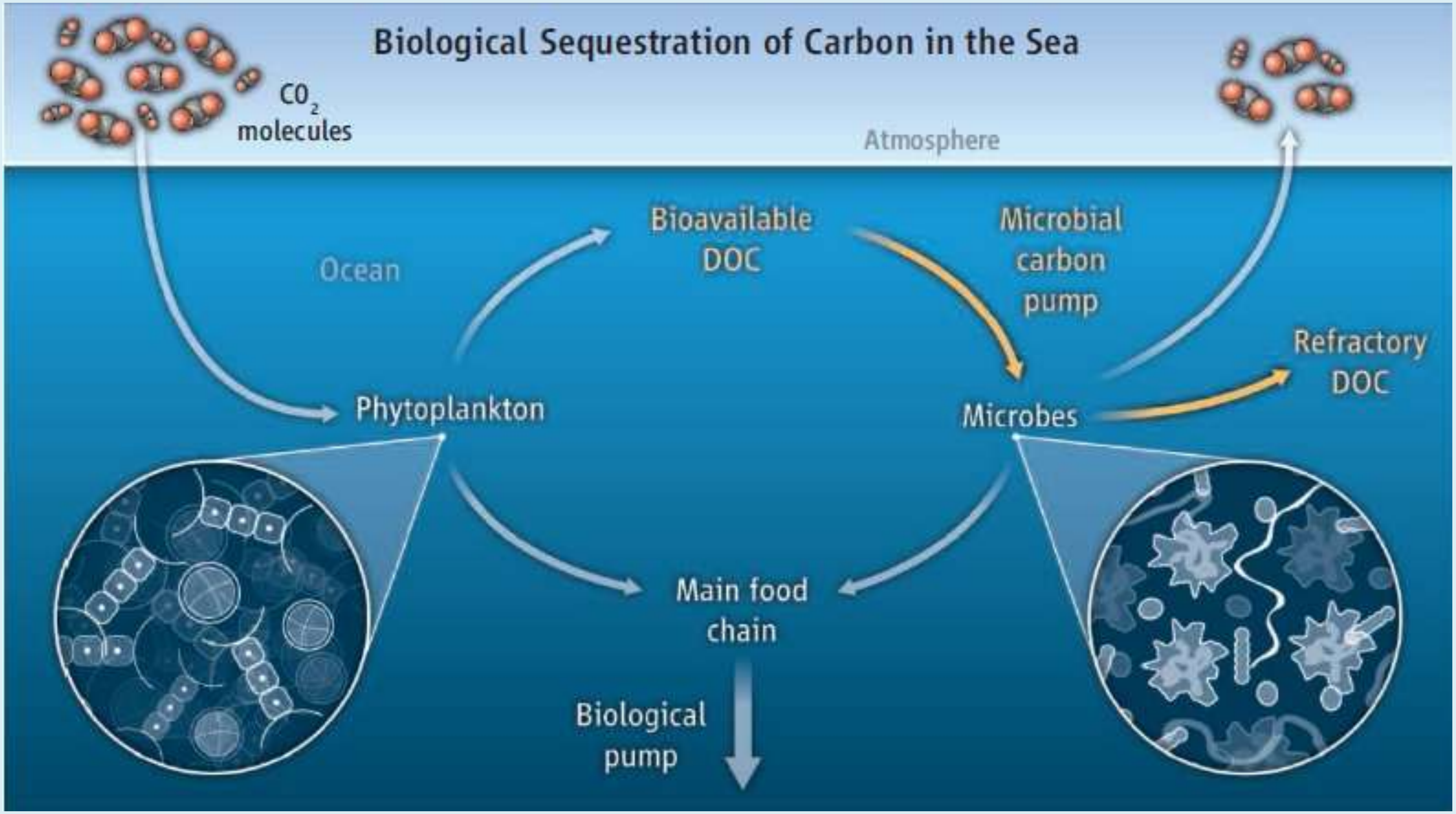
- Replanting trees on land in USA:
  - Increases annual sequestration by 2.2 to 9.5 metric tons per acre for 120 years
  - Good forestry practices implemented
  - 40 to 60 billion tons over 50 years
  - 0.8 to 1.2 billion metric tons per year
  - 13% to 20% of nation's CO_2 emission in 2006

cabiblog.typepad.com

epd372.blogspot.com

HTWI
High Tech Workforce Initiative

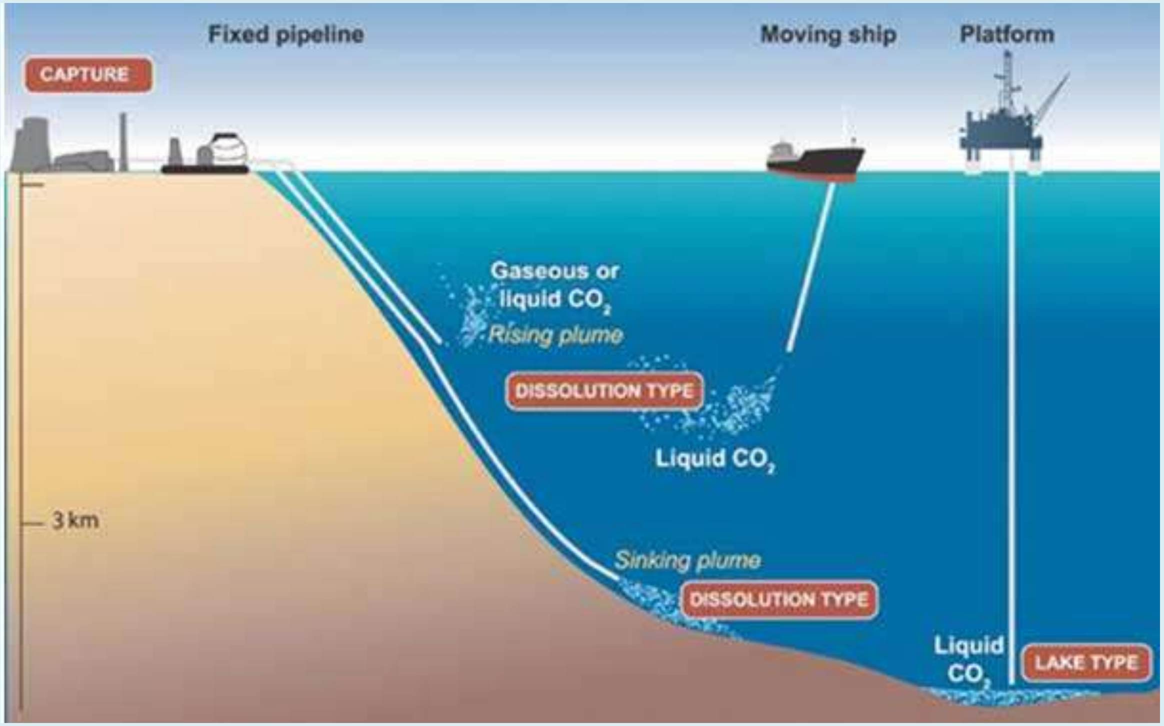
Ocean Biological Sequestration



theresilientearth.com

Ocean Sequestration

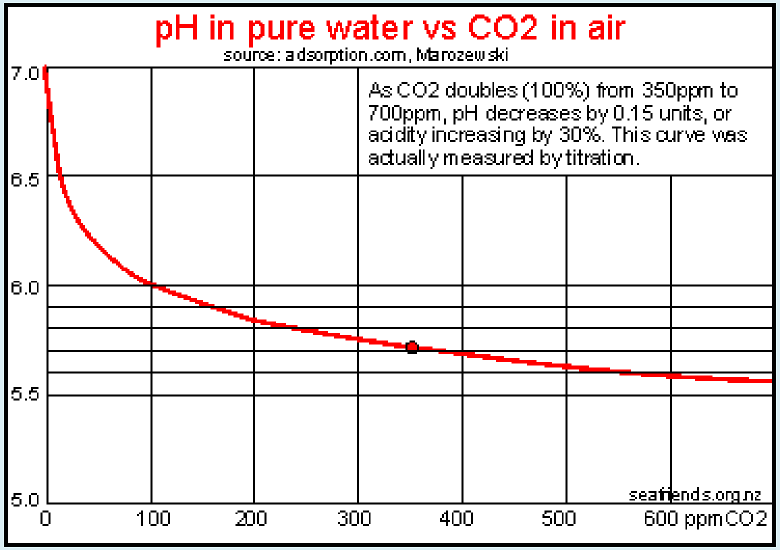
- Dissolution by droplet plume or dense plum
- Dispersion by towed pipe or dry ice
- Isolation creating a CO_2 "lake"



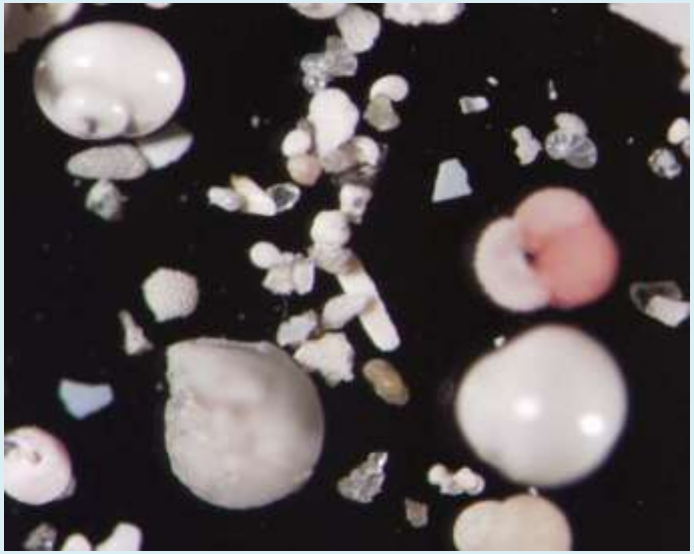
powerplantccs.com

HTWI
High Tech Workforce Initiative

Potential Problem with Ocean CO_2 Sequestration?



seafriends.org.nz



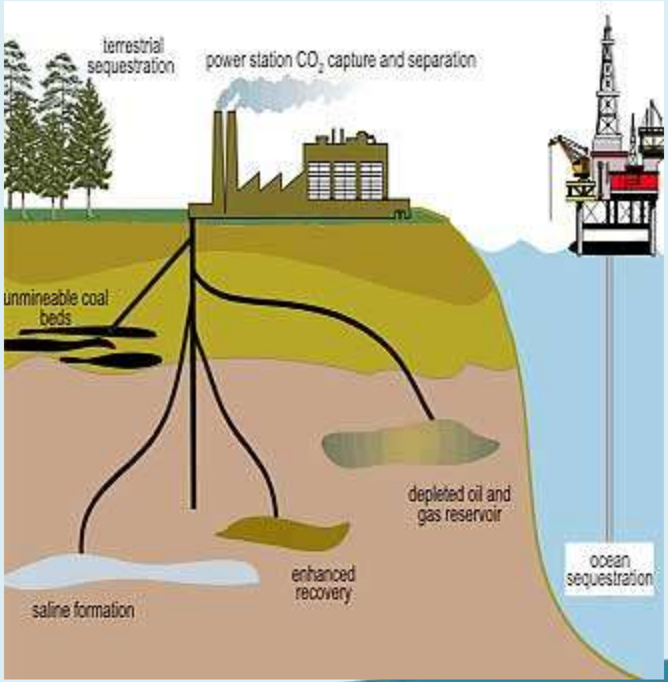
blogs.nature.com

"Anthropogenic carbon dioxide has been accumulating in the oceans, lowering both the concentration of carbonate ions and the pH , resulting in the acidification of sea water. Previous laboratory experiments have shown that decreased carbonate ion concentrations cause many marine calcareous organisms to show reduced calcification rates." Andrew Moy, *Nature Geoscience*, 2, 276 – 280 (2009)

HTWI
High Tech Workforce Initiative

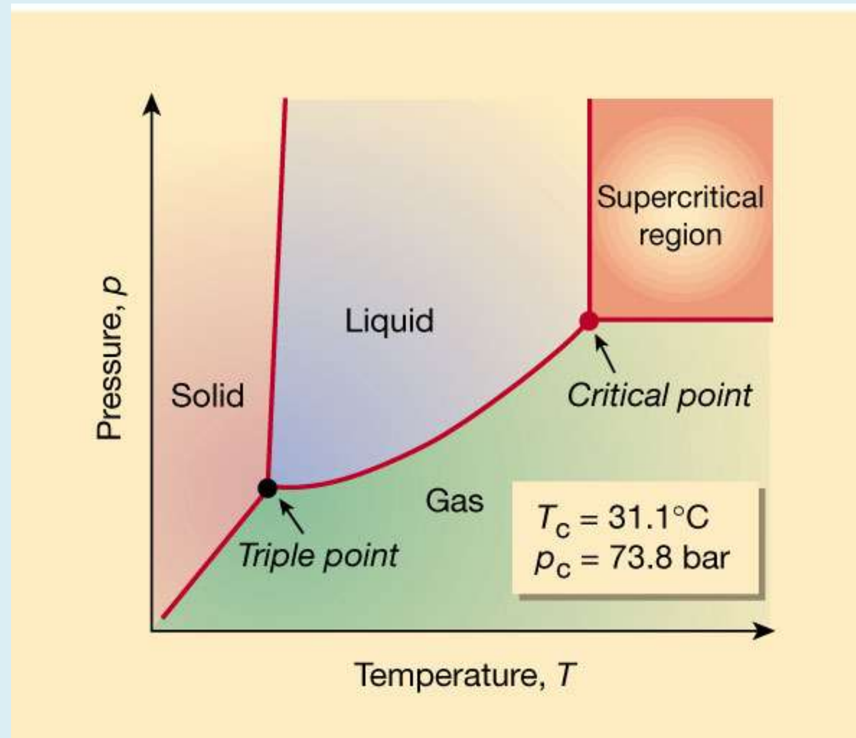
CO_2 Sequestration

- Geological
  - Depleted oil and gas reservoirs
  - Unmineable coal beds
  - Deep saline aquifers



Compression of CO_2

i.ytimg.com/vi/8AN_XMcD3yI/0.jpg

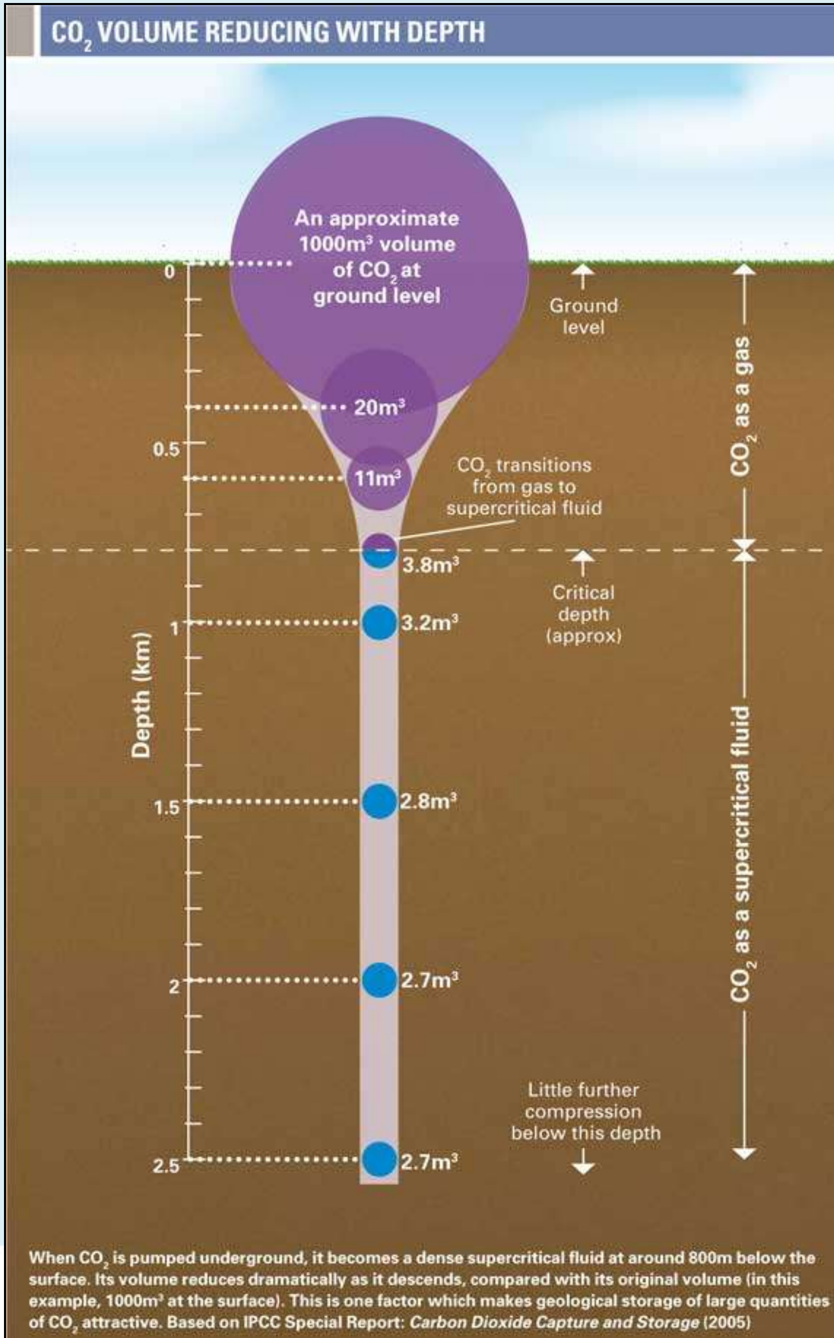


www.nature.com/.../n6783/images/405129aa.2.jpg

Triple Point of CO_2

- 217 K (- 57^{o}C)
- 517 kPa (5.1 ATM)

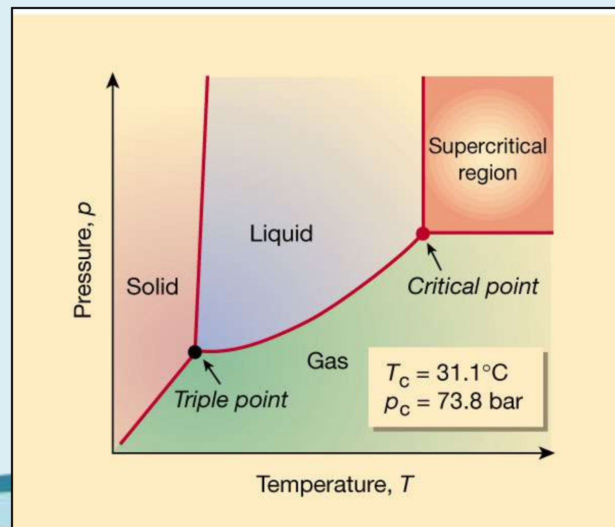
HTWI
High Tech Workforce Initiative



www.bp.com/.../fr21ccs_voludepth180x144.jpg

Compression of CO_2

"When CO_2 is pumped underground it becomes a dense supercritical fluid around 800 m below the surface."



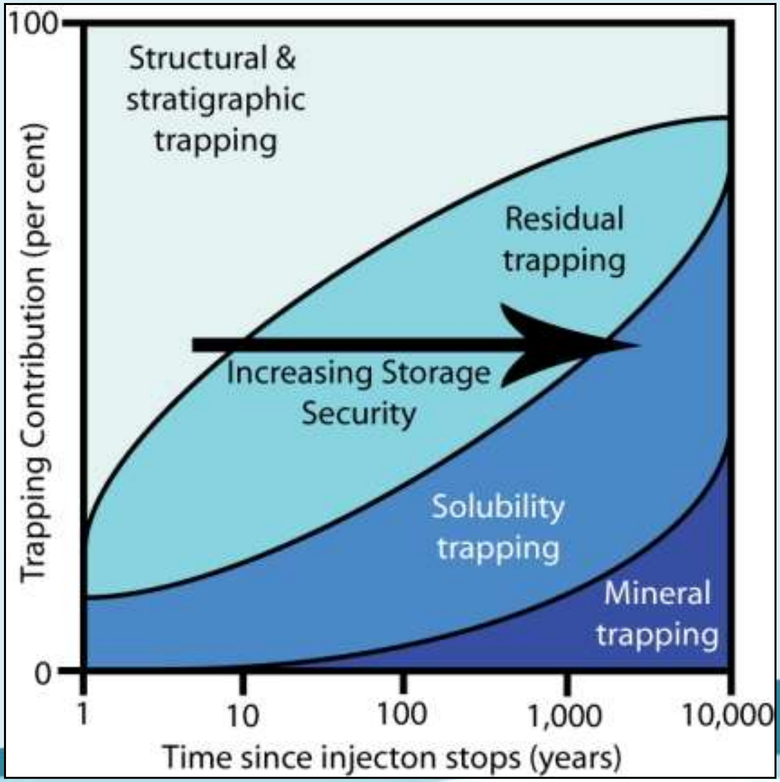
www.nature.com/.../n6783/images/405129aa.2.jpg

HTWI
High Tech Workforce Initiative

CO_2 Sequestration Mechanism

The increasing storage security of CO_2 may take anywhere from 10 to 10,000 years.

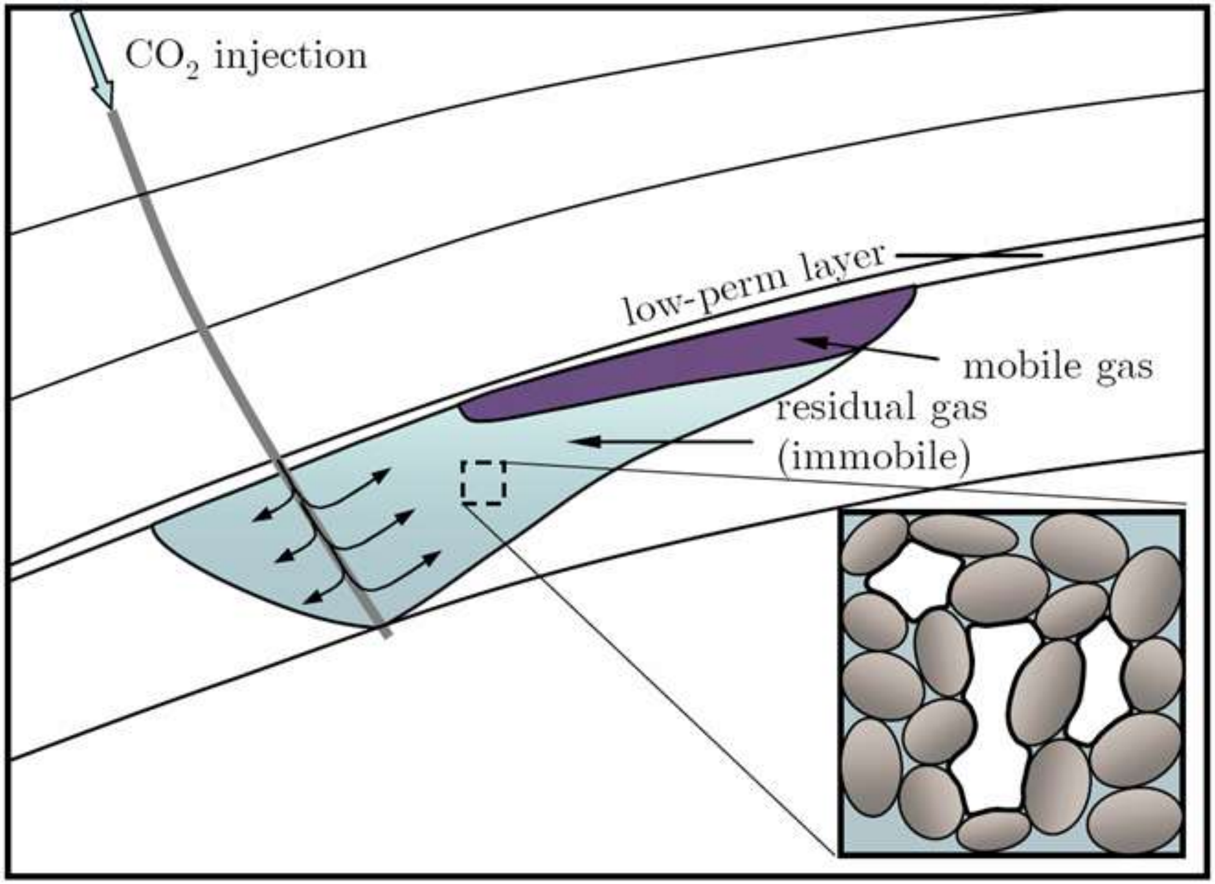
- Structural Storage
- Residual Storage
- Solubility Storage
- Mineral Storage



HTWI
High Tech Workforce Initiative

CO_2 Storage Mechanism

Structural → Residual → Solubility → Mineral



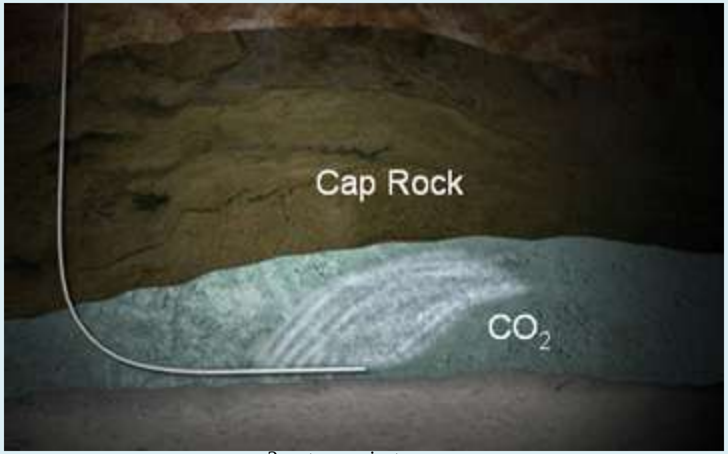
juanesgroup.mit.edu

HTWI
High Tech Workforce Initiative

CO_2 Storage Mechanism

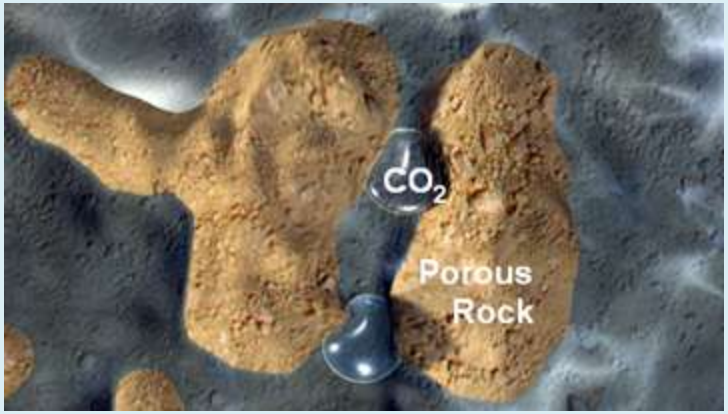
Structural → Residual → Solubility → Mineral

St



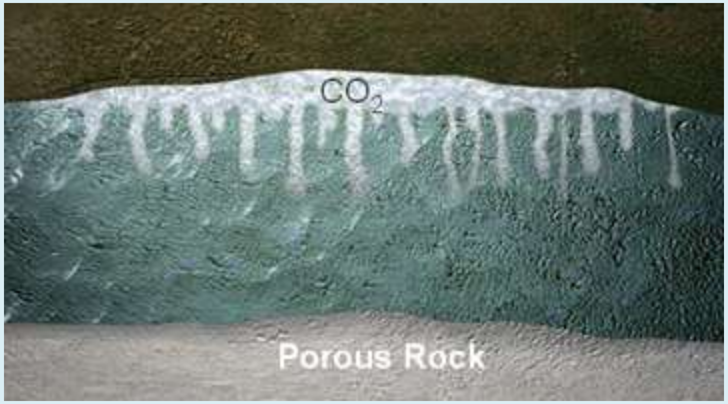
co2captureproject.org

R



co2captureproject.org

So



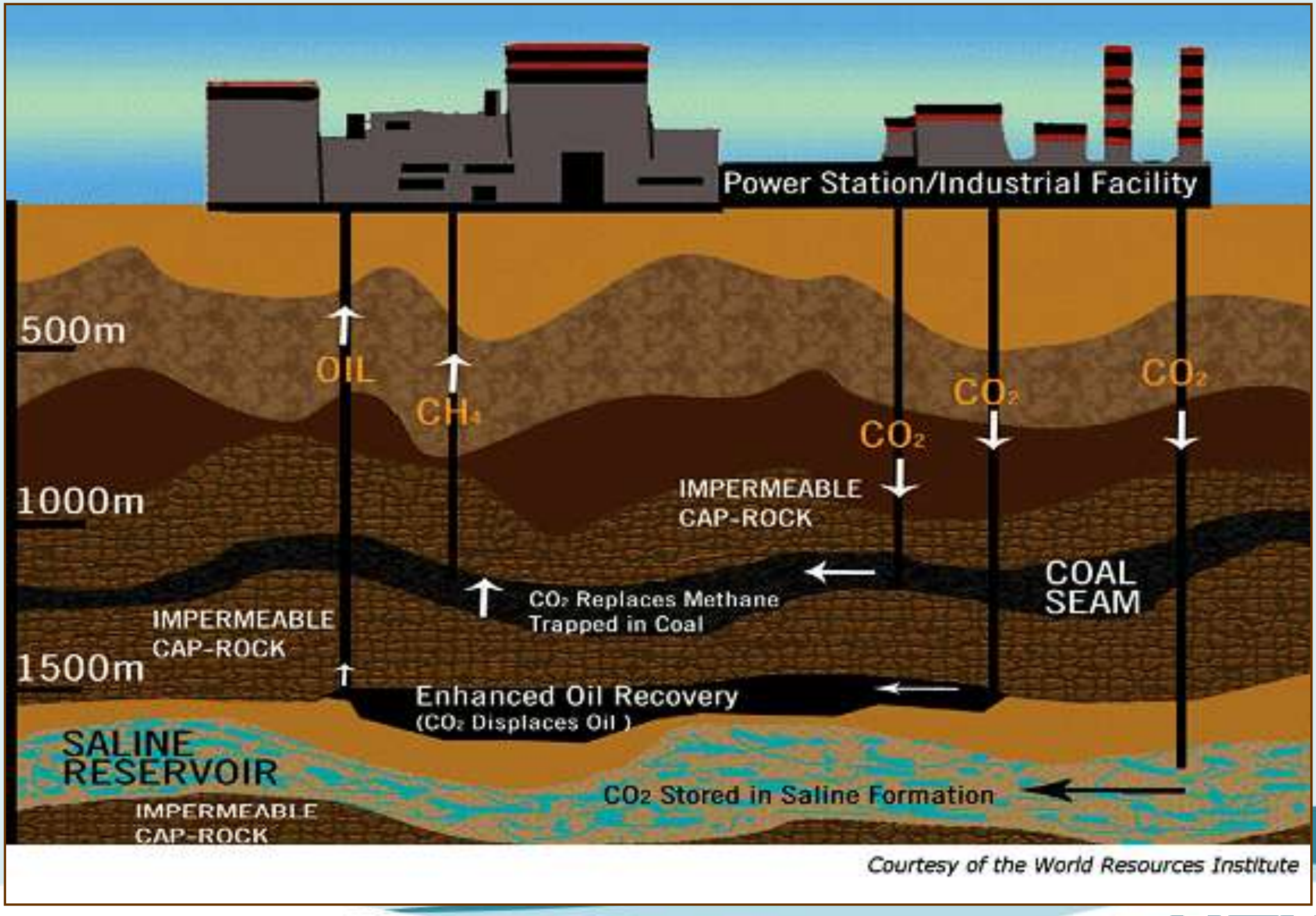
co2captureproject.org

M

co2captureproject.org

HTWI
High Tech Workforce Initiative

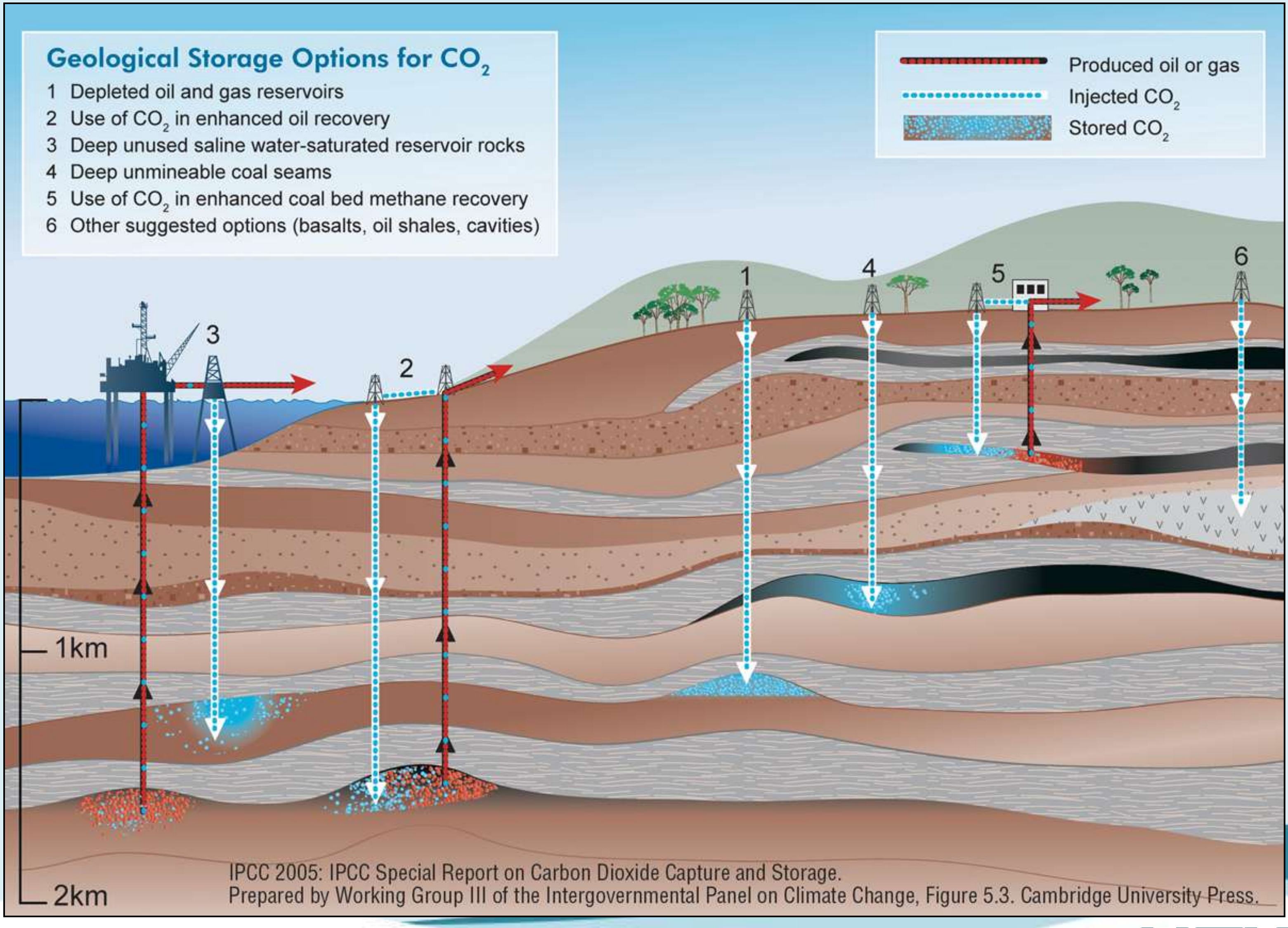
Geological CO_2 Sequestration



dcnr.state.pa.us

HTWI
High Tech Workforce Initiative

Summary of Geological Sequestration



flowserve.com

HTWI
High Tech Workforce Initiative

Sequestration Sites

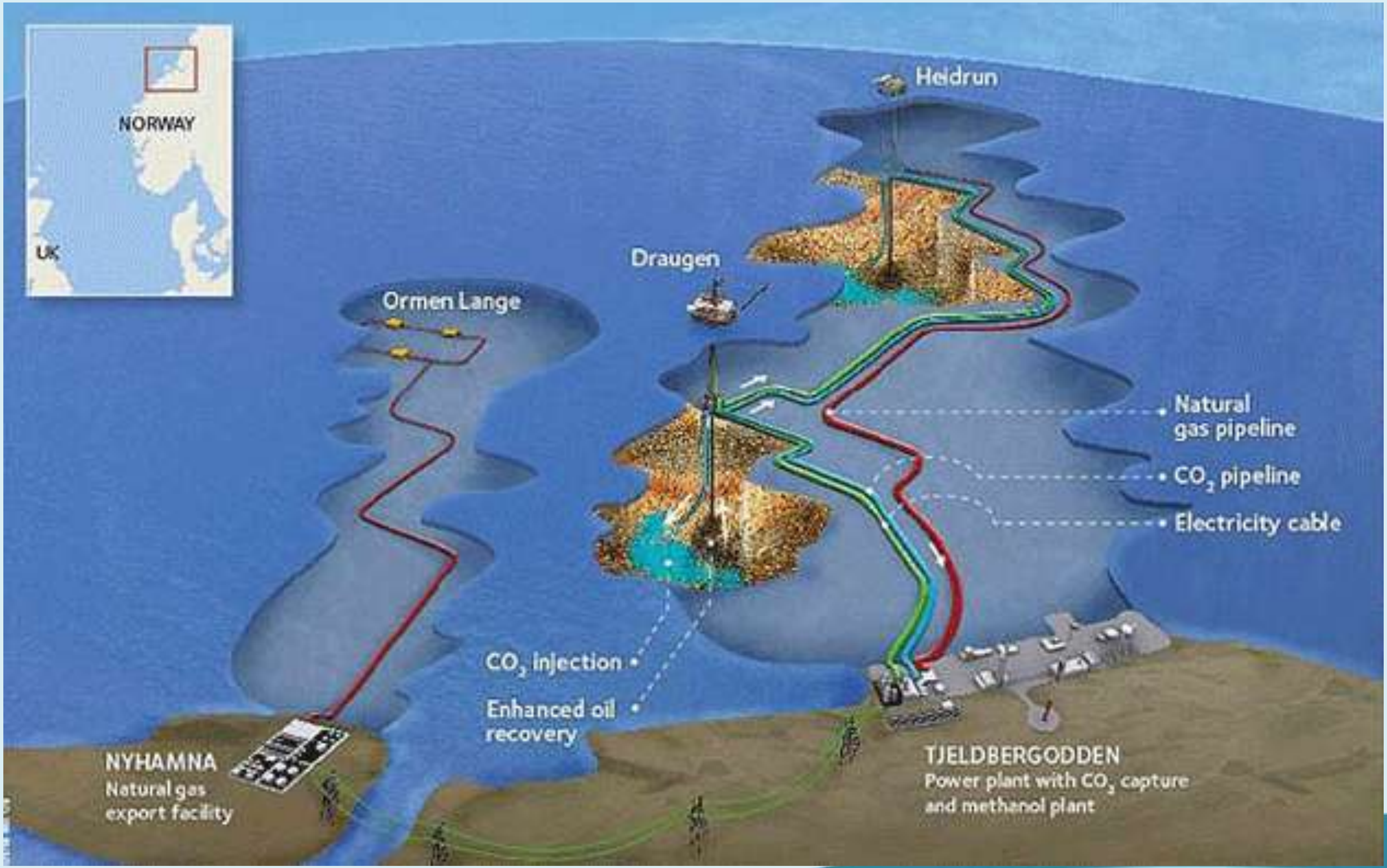
- Current and Planned Projects

[world storage sites SCCS](http://www.geos.ed.ac.uk/sccs/storage/storageSitesFree.html)

http://www.geos.ed.ac.uk/sccs/storage/storageSitesFree.html

  - 38 Carbon Dioxide Capture and Storage Projects
  - 15 Carbon Dioxide Storage Only Projects
  - Additional 30 Carbon Dioxide Capture and Storage Projects recently announced

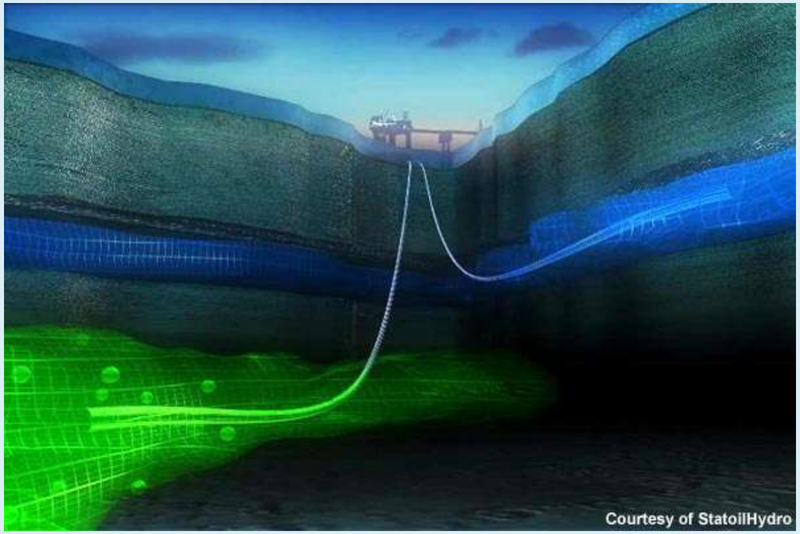
Sequestration of CO_2 in Norway



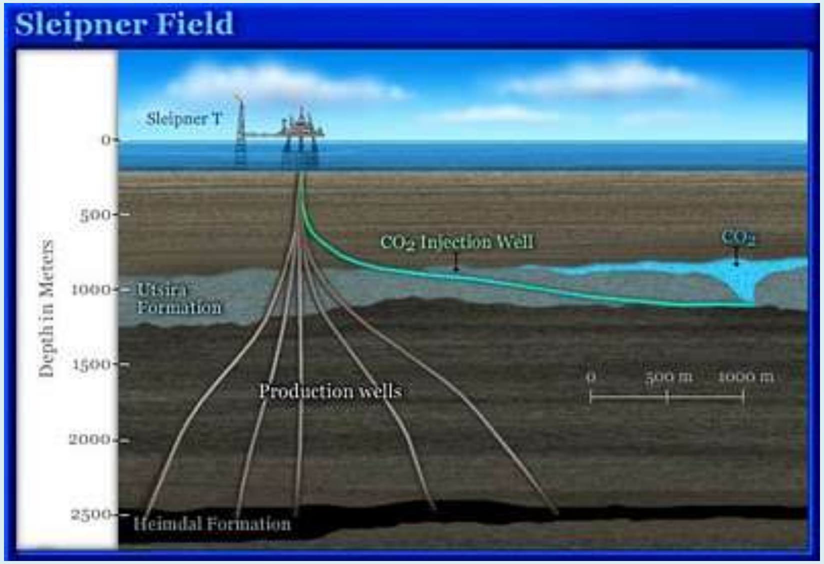
www.statoil.com/.../tjeldbergodden_630.gif

HTWI
High Tech Workforce Initiative

Sequestration of CO_2 in Norway



blog.norway.com



newenergynews.blogspot.com

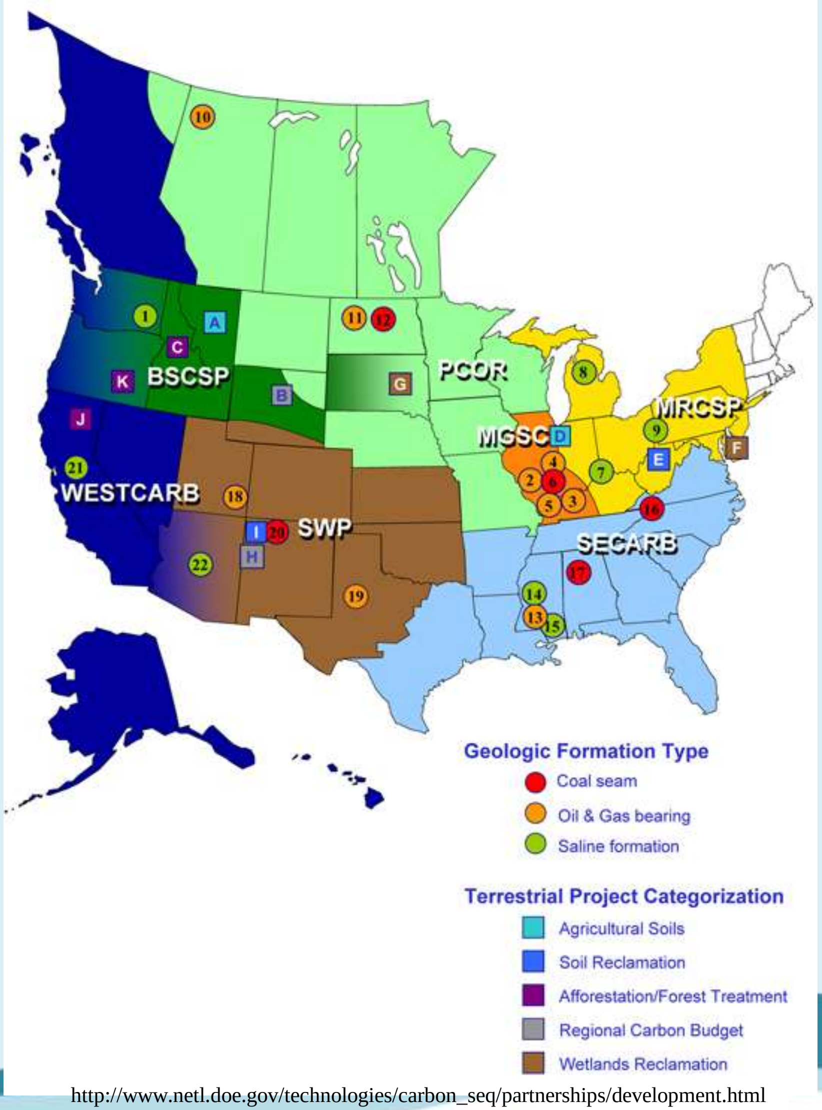
sequestration.mit.edu

http://www.bellona.org/ccs/Artikler/storage

HTWI
High Tech Workforce Initiative

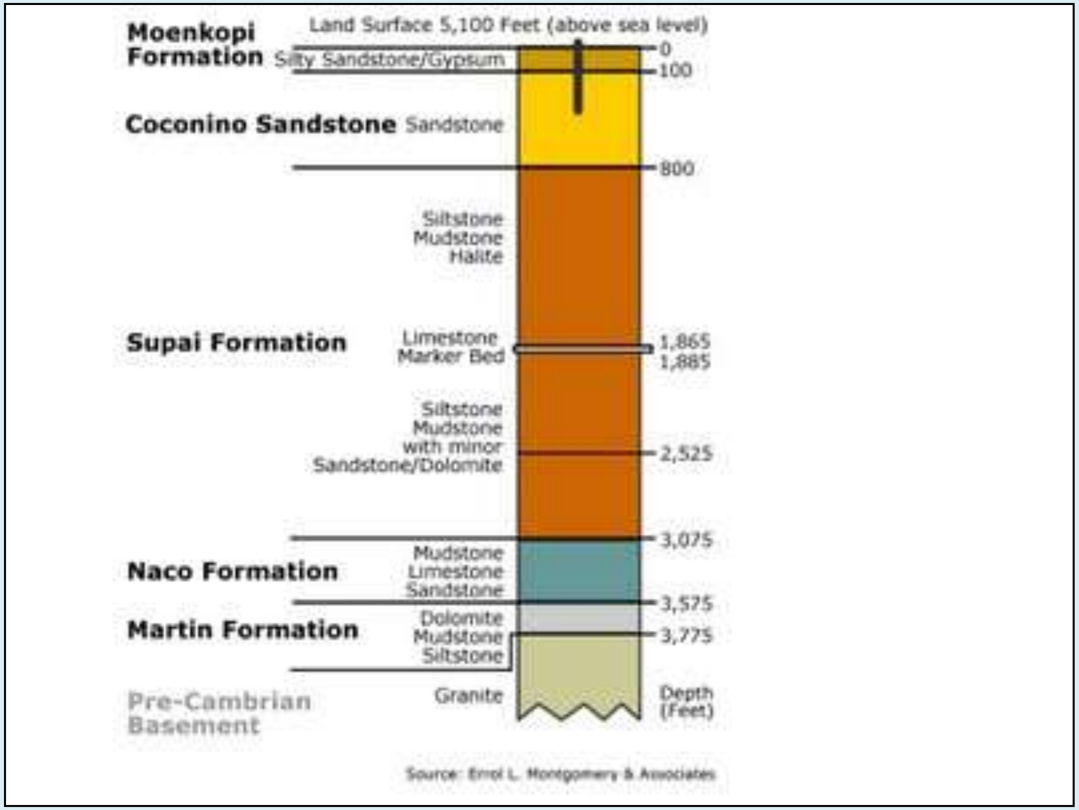
US Regional Carbon Sequestration Projects

- <u>Characterization Phase</u>
  (2003 – 2005)
  characterized opportunities for carbon sequestration
- <u>Validation Phase</u>
  (2005 – 2010)
  small scale field tests
- <u>Development Phase</u>
  (2008 – 2017)
  Conduct large volume carbon storage tests



http://www.netl.doe.gov/technologies/carbon_seq/partnerships/development.html

Arizona Carbon Sequestration Projects



arizonageology.blogspot.com

arizonageology.blogspot.com

Arizona Public Service (APS)
Cholla Drill Site
2000 tons CO_2 injected into saline formation

HTWI
High Tech Workforce Initiative

Survey 3

Which of the following carbon sequestration storage options will not be utilized much in the future?

A. Depleted oil and gas reservoirs

B. Oceans

C. Unmineable coal beds

D. Deep saline aquifers

Type them in your chat window

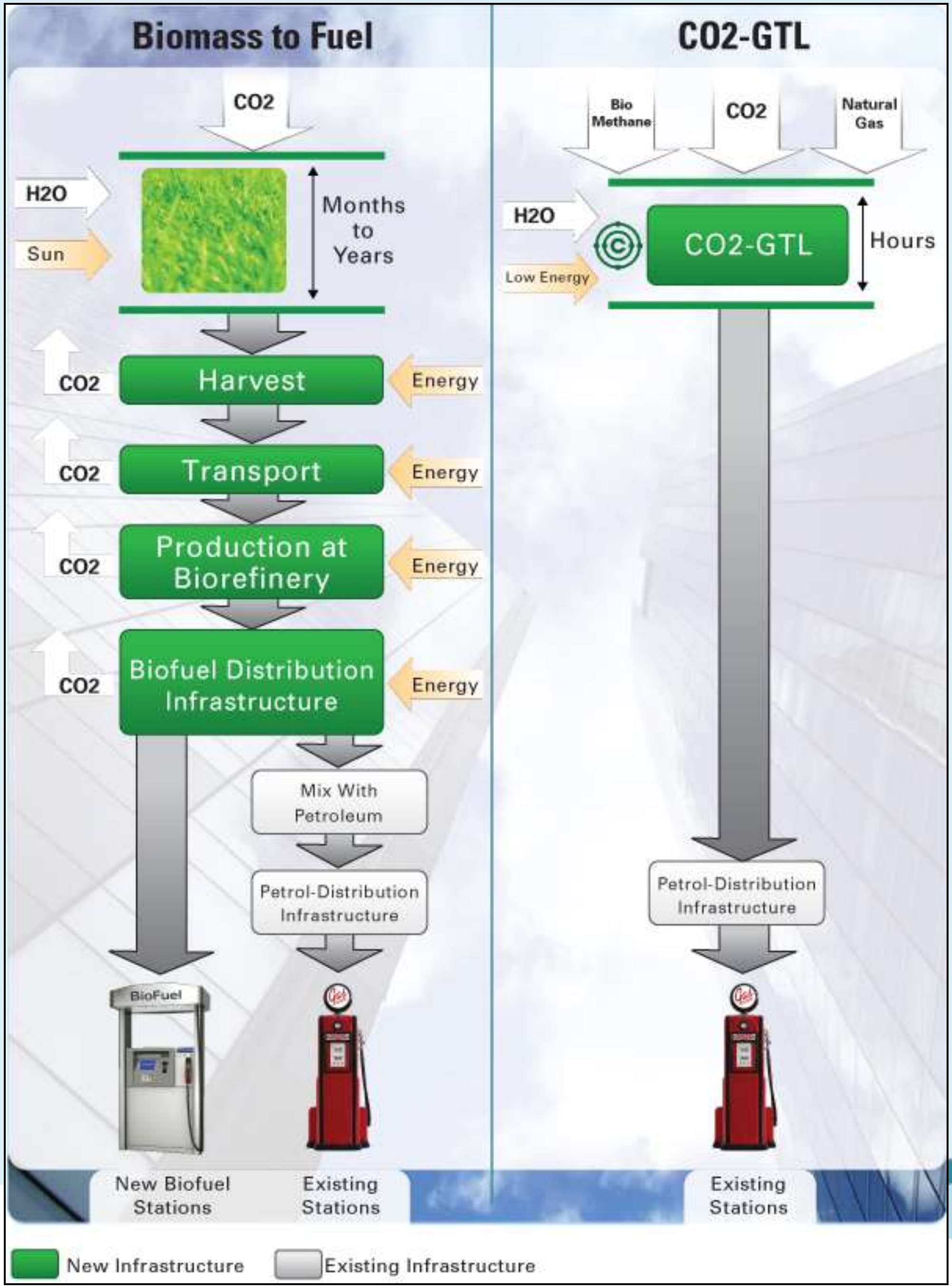
Recycling CO_2 into Commercial Products

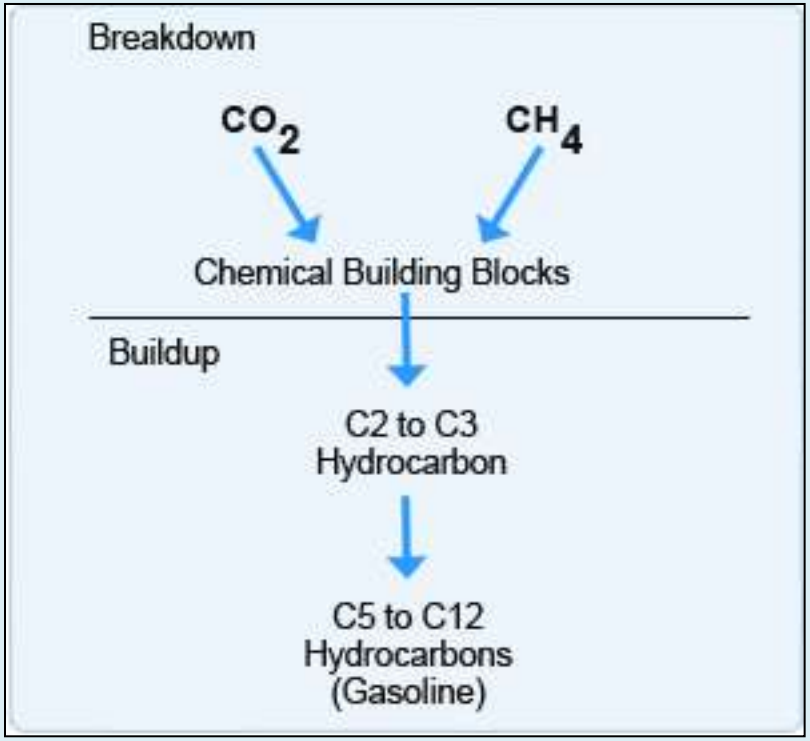
Potential CO_2 Solutions

HTWI
High Tech Workforce Initiative

Recycling CO_2 to Commercial Products

- Carbon Sciences
  - Uses inexpensive, renewable bio-molecules (encapsulated) to catalyze chemical reactions transforming CO_2 and water to fuel.
  - Key to their process:
    - Able to prolong the life of the enzyme (biocatalyst) to reduce costs.
    - Reduced reaction time from 10 hours to minutes (8 – 10)
    - Hg kills catalyst so flue gas must be clean

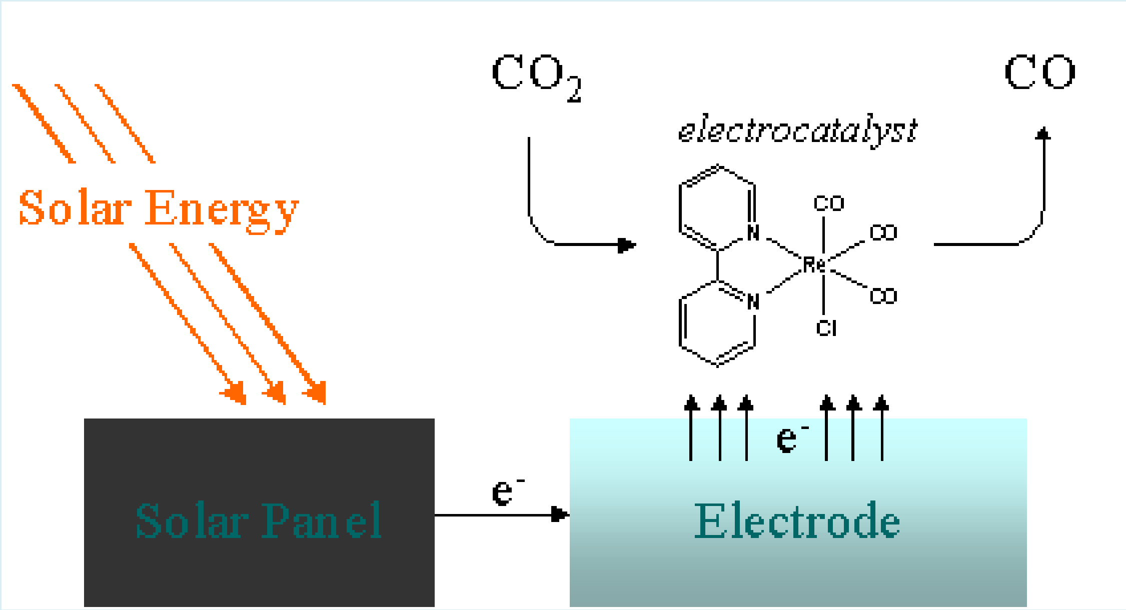




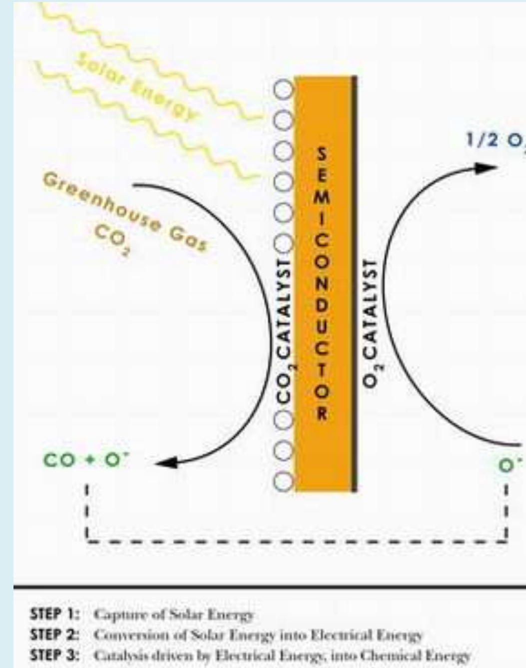
$$CH_4 + CO_2 \rightarrow (C_{5\text{-}10}H_n) + H_2O$$

HTWI
High Tech Workforce Initiative

Recycling CO_2 to Commercial Products



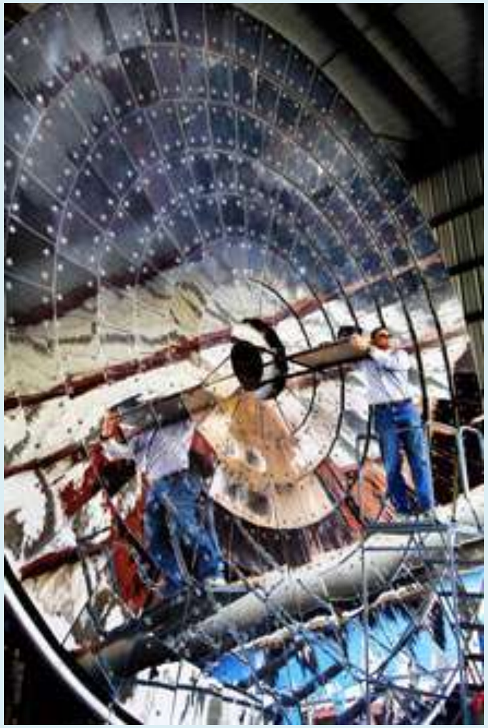
jacobsschool.ucsd.edu



- Kubiak (UCSD) – uses semiconductors to trap solar energy and covert it to electrical energy which is then used to split the CO_2 into CO and O_2

Recycling CO_2 to Commercial Products

- Sandia National Lab
  - invented a reactor containing a ceramic ring made of iron oxide and cobalt. A solar concentrator heats the ceramic material to 2,700 degrees Fahrenheit, forcing it to give up its oxygen.
  - The ring then rotates to a colder chamber containing CO_2.
  - The ceramic borrows oxygen atoms from the CO_2, leaving carbon monoxide, CO.
  - CO can be used to make fuel.



technologyreview.com

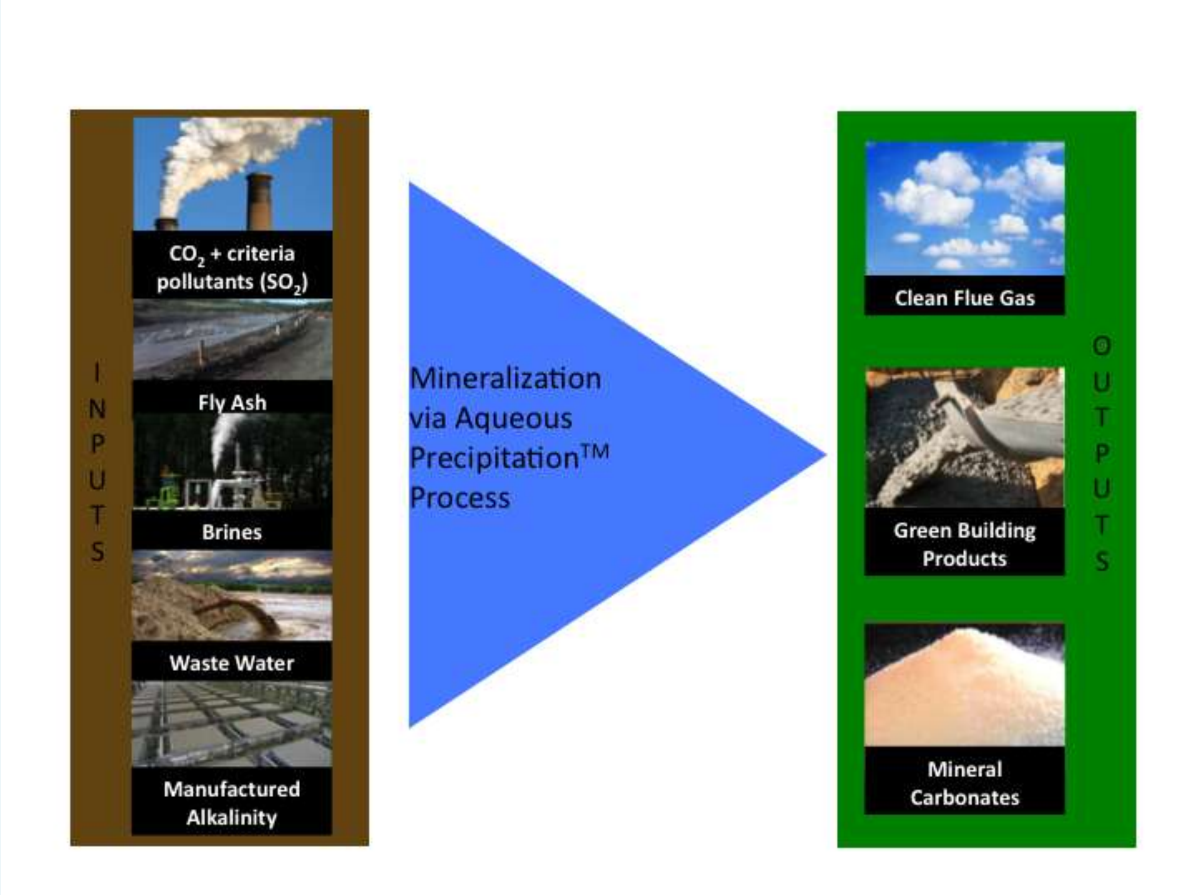
HTWI
High Tech Workforce Initiative

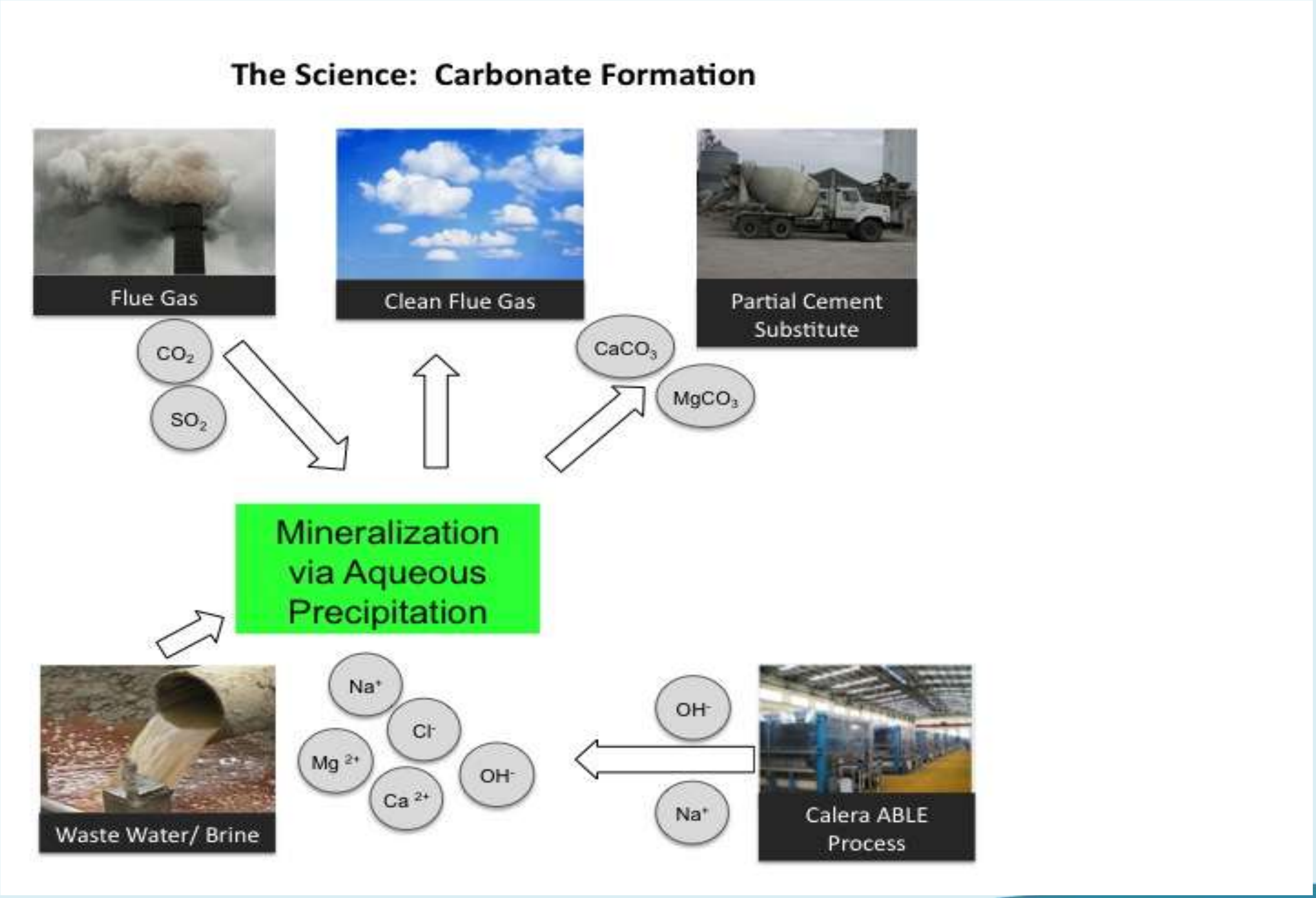
Recycling CO_2 to Commercial Products

Calera

Use flue gas CO_2 and combine it with sea water to make cement.

http://calera.com



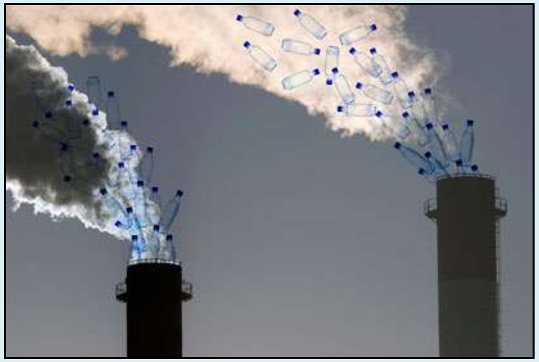


http://calera.com/index.php/technology/the_science/

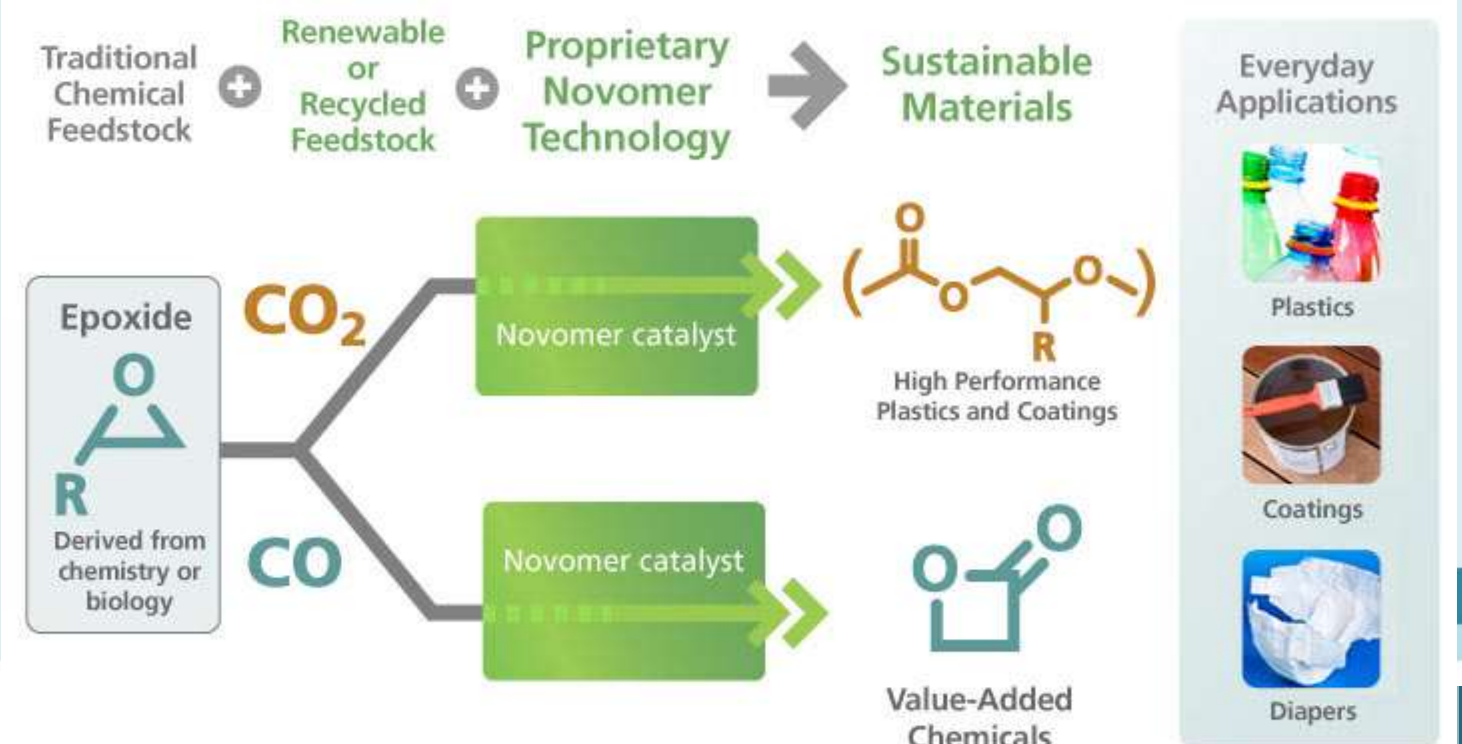
Recycling CO_2 to Commercial Products

Novomer: A green plastics company

- utilizes CO_2 and CO feed stocks to produce plastics for specific high-tech markets.



www.rsc.org/.../co2-chimney-410_tcm18-187444.jpg

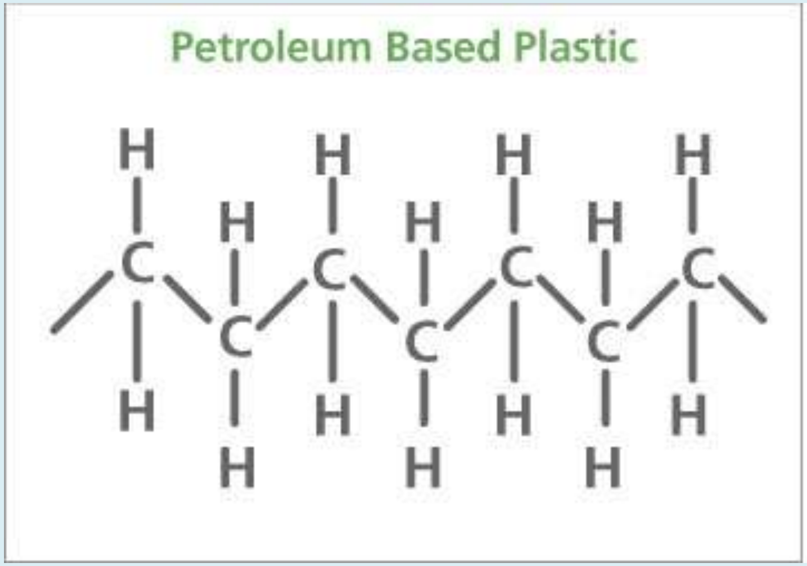


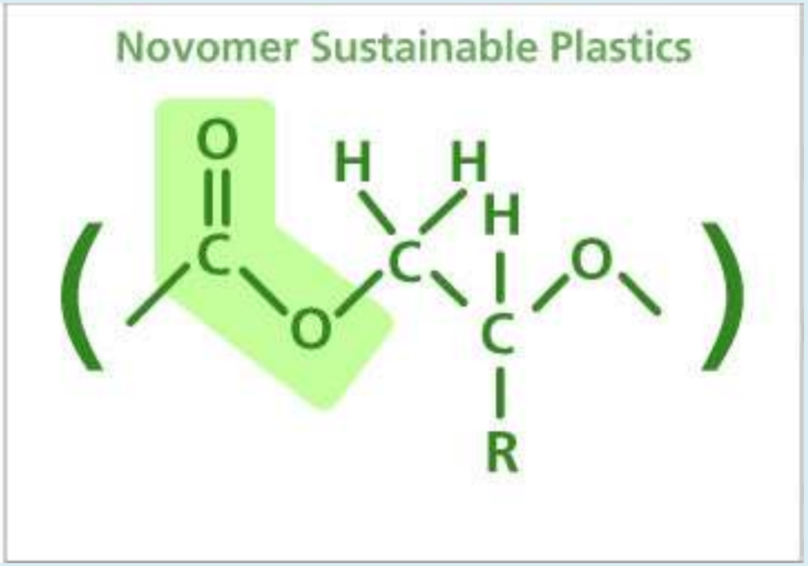
http://www.novomer.com/?action=tech_overview

HTWI
High Tech Workforce Initiative

Recycling CO_2 to Commercial Products

- Novomer: http://www.novomer.com





Polyethylene is a long chain of carbon molecules derived from natural gas or crude oil.

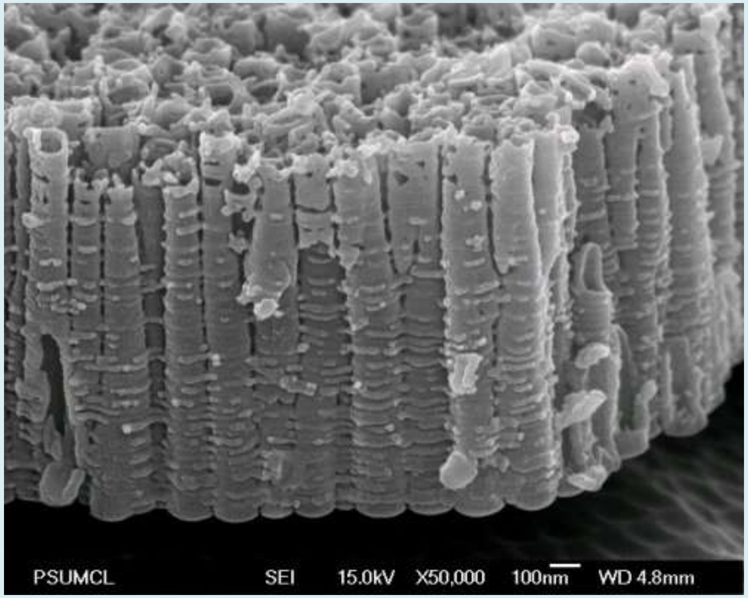
Direct incorporation of CO_2 into the molecular backbone to create a more sustainable material.

http://www.novomer.com/?action=tech_how_it_works

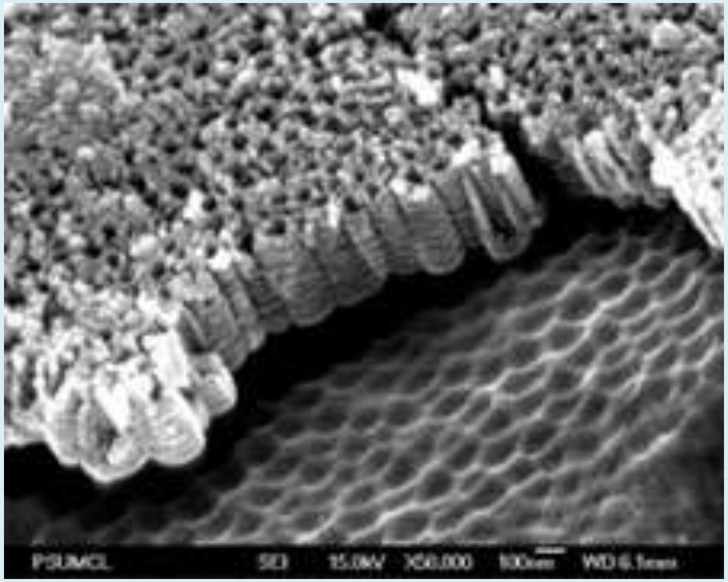
HTWI
High Tech Workforce Initiative

Recycling CO_2 to Commercial Products

- Grimes (Penn State)
  - Designed a photocatalyst of nitrogen-doped titania nanotubules sputter coated with an ultrathin layer of platinum or copper catalyst.

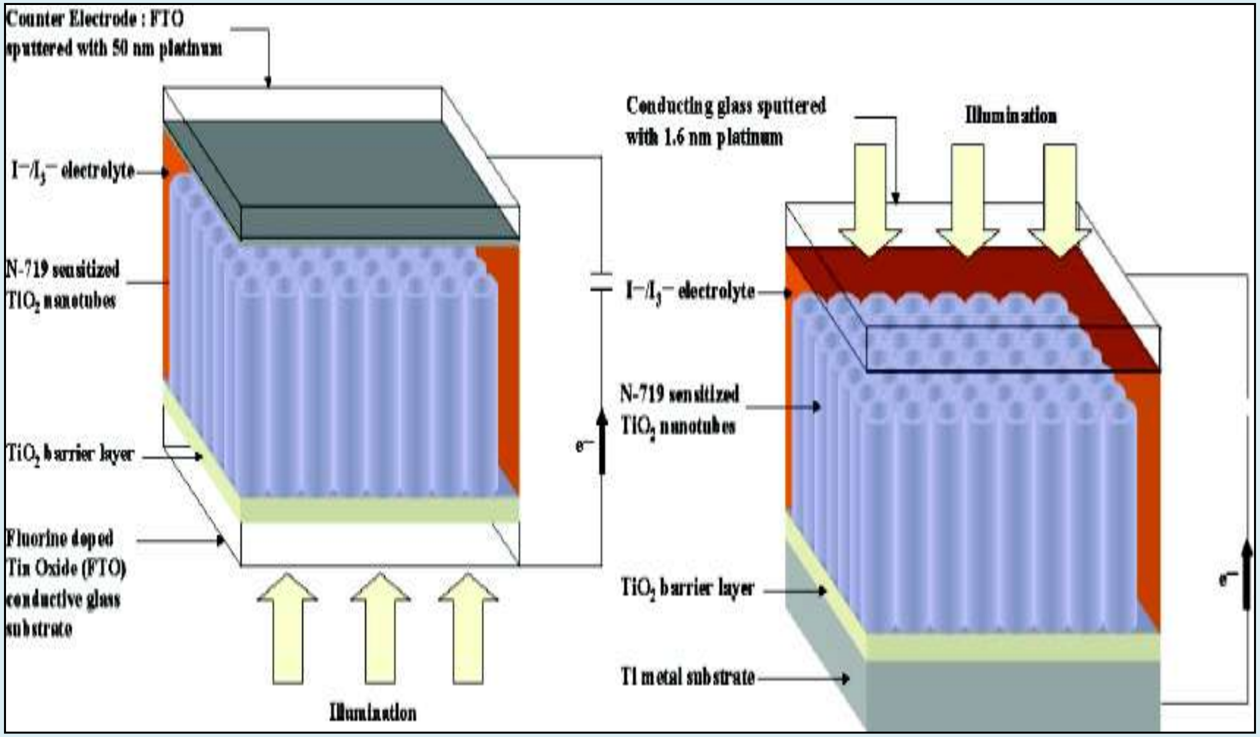


http://images.iop.org/objects/ntw/news/5/1/6/crosssection.jpg

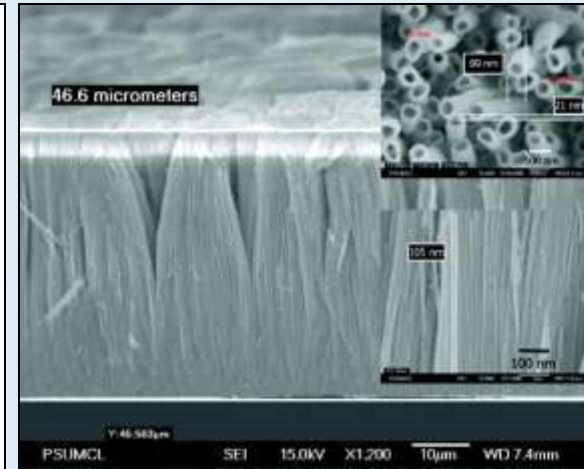


http://www.mri.psu.edu/articles/BC/faculty/CraigGrimes/grimes_c_3.jpg

HTWI
High Tech Workforce Initiative



http://spie.org/x25474.xml?ArticleID=x25474

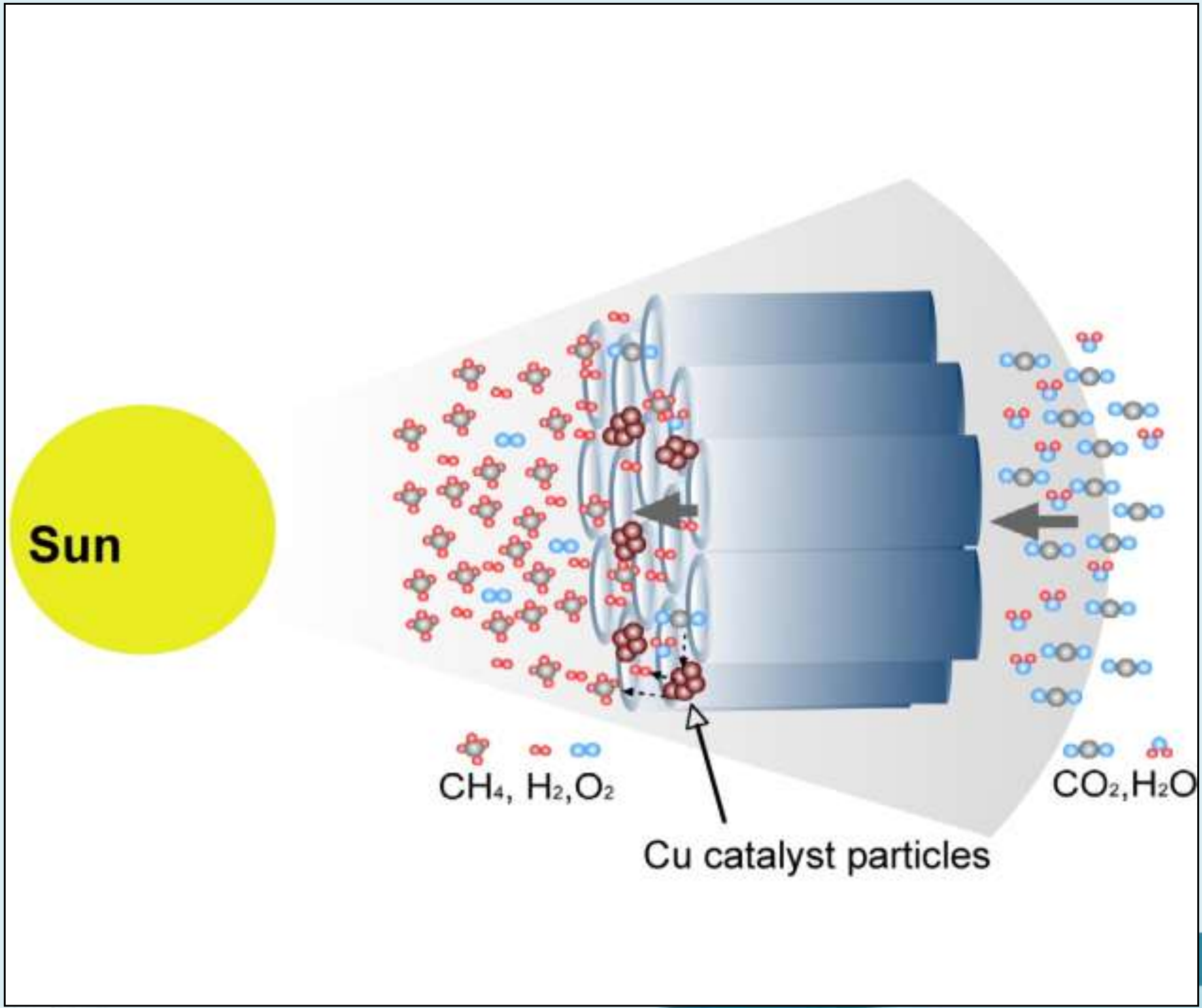


http://spie.org/Images/Graphics/Newsroom/Imported/1148/1148_fig1.jpg

The titania captures the high energy UV while the nanotubules provide the surface area for the reactions to occur.

Captured CO_2 is combined with water vapor to react and make hydrogen (H_2), oxygen (O_2) and methane (CH_4) gases.

$CO_2 + H_2O \rightarrow CH_4 + H_2 + O_2$



http://www.newswise.com/images/uploads/2009/02/27/fullsize/Flow-Thru_2.jpg

Recycling CO_2 to Commercial Products

- Global Research Technologies, LLC (GRT)
  - Klaus Lackner, Professor, Columbia University's Earth Institute & School of Engineering
  - Membrane technology is used to extract CO_2 out of ambient air.
  - A type of artificial trees

http://ehp.niehs.nih.gov/docs/2009/117-4/trees.jpg

Survey 4

In your opinion, which type of the following CO_2 recycling methods will be most successful?

A. Celera’s cement
B. Kubiak’s semiconductor solar cell (CO)
C. Novomer’s plastic bottles
D. Carbon Science’s gasoline
E. Grimes nanotechnology solar cell (CH_4)

HTWI
High Tech Workforce Initiative

Type them in
your chat
window

Acknowledgements

- Diversified Energy
  - Phillip Brown & Dave Thompson
- HTWI Externship Program
  - Lizette Acosta
- MCCCD Office of Workforce Development
  - MATEC & Mark Viquesney
- National Science Foundation
  - High Tech Workforce Development Grant

HTWI
High Tech Workforce Initiative

Help us become better

Please complete this quick 1 minute survey to help us become better and to let us know what webinars you would like to see in the future.

http://www.questionpro.com/t/ABkVkZIwJD

HTWI
High Tech Workforce Initiative

Thank You for attending today's HTWI webinar

Carbon Capture and Storage (CCS) and Potential CO_2 Solutions

Hosted by MATEC Networks

www.matecnetworks.org

HTWI
High Tech Workforce Initiative