CO_2 Capture and Storage - The Essential Bridge to the Hydrogen Economy

Presentation at the Second Annual Conference on

Carbon Sequestration

May 5-8, 2003

Alexandria, Virginia

by

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Presentation Overview

Background of SFA Pacific relative to H_2 & CO_2 mitigation

Why hydrogen as a fuel?

- H_2 has some inherent problems relative to traditional fossil fuels
- Fuel cells & CO_2 capture/storage are the keys to the H_2 economy

Hydrogen is already a large, commercially well proven industry

- Hydrogen production & uses
- Hydrogen transportation & distribution

CO_2 capture & storage is also a large commercially well proven industry

Economics beats technology or "show me the money" for CO_2 capture & storage

- We expect CO_2 capture & storage subsidies or incentives in the future

Background of Recent SFA Pacific H_2 & CO_2 Mitigation Related Projects & Presentations

Private industry sponsored analyses

- Major private Multisponsored analysis of CO_2 mitigation options
- Major private Multisponsored analysis of syngas & gas to liquids
- CO_2 capture & storage analysis for the BP led CO_2 Capture Project (CCP) & the TransAlta led Canadian Clean Power Coalition (CCPC)
- H_2 production & infrastructure costs for auto & oil companies plus partial DOE funding via NREL, July 2002 report NREL/SR-540-32525

Presentations

- Analysis of CO_2 control options for electric power generation for: GHGT-4 in 1998, GHGT-5 in 2000 & National Academies in 2002
- Analysis of the hydrogen economy for National Academies in 2003

Most of our H_2 & CO_2 work is for industrial energy companies

SFA Pacific's Hydrogen Economy Work

SFA Pacific was part of the team that developed the road map for the California Fuel Cell Partnership in 2000

Nine major auto & oil companies interested in fuel cell vehicles & the associated hydrogen requirements formed the International Hydrogen Infrastructure Group (IHIG) in 2001

The IHIG contacted SFA Pacific originally in 2001 & again in 2002 requesting a screening analysis estimate of hydrogen production & infrastructure costs to support FC vehicles

- Due to secondary cost sharing by U.S. DOE via NREL our IHIG analysis was made public in July 2002 as report NREL/SR-540-32525

Currently assisting the National Academies H_2 Committee

Why Hydrogen as a Fuel?

Hydrogen is the most abundant element in the universe

When used as a fuel H_2 produces only clean energy & H_2O

Energy futurists see a logical progression from wood to coal to oil to NG to H_2 as standard of living & technologies improve

- Each fuel switch is cleaner, more efficient & lower in CO_2 emissions

Energy futurists also like H_2 from sustainable renewables

- However, H_2 from fossil fuels is cheaper until the fossil fuel age peaks in 50-100 years making fossil fuels increasingly more expensive

The hydrogen economy concept is quite interesting, long-term

- However, the short-term challenge is developing a hydrogen infrastructure while H_2 from fossil fuels is still much cheaper

Hydrogen Has Some Inherent Problems as It Is Not a Fuel Source, Merely an Energy Carrier

Like electricity, H_2 is not a naturally occurring fuel as NG & coal

Like electricity, H_2 production is expensive & inefficient

Like electricity, H_2 transport & storage is expensive & difficult

H_2 has the lowest energy density of any energy carrier

- High costs or heavy containers to improve H_2 energy density
  - Over 65 kg container weight per 1 kg gaseous or hydrate hydrogen
  - Even as expensive liquid H_2 still only 27% energy density of gasoline

H_2 is dangerous to use - big explosive range & invisible flame

- Current codes for H_2 use & storage are onerous

H_2 use is inefficient due to the large water formation & energy loss in the flue gas - LHV/HHV is 84.6% or 15.4% HHV losses

Fuel Cells and CO_2 Avoidance are Keys to the Hydrogen Economy

Fuel cells are unique in their direct conversion of chemical energy to electric energy

- Fuel cells can also operate at low temperature & can be reversible
- However, exploiting these exciting attributes of fuel cells hinges on developing effective H_2 production & H_2 infrastructure

The global warming issue is likely the essential bridge to begin developing the long-term hydrogen economy

- Assuming global warming becomes a serious problem & we have the "stomach" to address the honest costs of effective CO_2 mitigation
- Although H_2 from renewables is "politically" more correct & essential for the long-term, it is clearly more economical to make H_2 from fossil fuels with CO_2 capture & storage in the short-term

Hydrogen is Already a Large, Commercially Well Proven Industry

World commercial H_2 production is currently >40 billion scf/d

- Equivalent to 133,000 MW_{th} or 75,000 MW_e if converted to electricity

Most H_2 is made from natural gas via steam methane reforming (SMR) yet 15% is made from oil residue or coal gasification

H_2 transportation & storage depends on amount & distance

- Pipelines for big users - worldwide over 10,000 miles with many in Texas, longest is 250 miles from Antwerp to Normandy @ 100 atm.
- Liquid hydrogen for moderate users - used through out California
- High pressure tube trailers for small users - used through out the world

Many H_2 advocates are unaware of this impressive experience

Current Industrial Hydrogen Markets

World ammonia & methanol consume > 30 billion scf/d H_2 or 100,000 MW_{th} energy & growing at 2-4%/yr

- Natural gas to liquid (GTL) fuels may significantly increasing this

World oil refineries consume > 10 billion scf/d H_2 or 33,000 MW_{th} & growing at 5-10%/yr due to reformulated cleaner fuels

- Less catalytic naphtha reforming byproduct H_2 & octane barrels
- More hydrotreating & hydrocracking to make octane & cleaner fuels
- More heavier crude oil require significant H_2 to convert to light liquids
- The oil refinery of the future will be much like California refineries today with H_2 manufacturing of about 800 scf per barrel of oil
- Typical refinery currently manufactures only 150 scf H_2 per barrel or less than 1/5 as much H_2 per barrel as a California refinery

CO_2 Storage is Also a Large Commercially Well Proven Industry

Over 20 years & currently > 30 million ton/year of commercial geologic CO_2 storage via enhanced oil recovery (EOR)

- **Extensive pipeline systems & with geologic CO_2 storage in depleted EOR oil fields for potential future reuse in other nearby oil fields**
- **Market price \$0.50/Mscf CO_2 (\$9.50/t CO2 or \$35/t C) - only 20% now from anthropogenic sources , however, anthropogenic CO_2 is poised to grow significantly as CO_2 reduction credits gain market value**

Over 20 years of commercial acid gas (H_2S & CO_2 from natural gas purification) injection into various geologic formations

- **Significant because H_2S is a lighter & more dangerous gas than CO_2 plus H_2S has a strong smell at only a few parts per million (ppm) in air**
  - **Therefore just the smallest H_2S leakage would have been easily detected years ago if there were any leakage problems**

CO_2 EOR Projects Using Anthropogenic CO_2

State/ Province	Plant Type	CO_2 Million t/yr	EOR Fields	Operator
Texas	Gas Processing	1.3	Sharon, Ridge, etc.	Exxon/Mobil
Colorado	Gas Processing	1.1	Rangely	Chevron
Oklahoma	Fertilizer	0.6	Purdy, Sho-Ven-Tum	Anadarko/Henry
Wyoming	Gas Processing	0.5	Lost Soldier, Wertz	Merit Energy
Alberta	Ethylene Plant	0.4	Joffre Viking	Numac Energy
Saskatchewan & North Dakota	Coal Gasification	1.7	Weyburn	EnCana
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North American Total 5.6 million tons per year CO_2

Sleipner Aquifer Project injects only 1.0 million tons per year CO_2

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Industrial CO_2 Capture Development Groups

Two major groups representing the two key energy industries: transportation fuels and electric power

CO_2 Capture Project or CCP- mostly oil companies

- Working to develop 2-4 large CO_2 capture demonstrations by 2008
  - 1 or 2 European & 1 Alaska North Slope, likely with natural gas to power
  - 1 Canadian, likely with pet coke gasification to power

Canadian Clean Power Coalition or CCPC- electric utilities

- Working to develop two even larger CO_2 capture demonstrations
  - Retrofit of an existing 300 MWe coal-fired power plant by 2007
  - A new advanced coal-based near zero emission power plant by 2010

Economics Beats Technology, Every Time

If the hydrogen economy is to develop within 50 years:

- The most cost effective options must be aggressively pursued for the two major energy applications - transportation fuels & electric power
- Major infrastructure challenges must be objectively addressed

Hydrogen economy will likely require:

- Some form of subsidies or incentive to support developing the infrastructure, however, any subsidies should be non-discriminatory, transparent & performance based to foster the lowest cost options

H_2 advocates must realize this may begin via H_2 from fossil fuels with CO_2 capture & storage if it is cheapest

- The key issue is getting H_2 infrastructure started, not waiting until H_2 from renewables becomes more competitive in 50-100 years

H_2 based Power Generation with CO_2 Storage

This is the easier application to start using hydrogen because

- It can develop without any changes in existing energy infrastructure & does not have to wait for advanced fuel cells to commercially develop
- Large existing coal-fired power plants are most interesting due their old age, high emissions & low efficiency

Gasification repowering old coal units with H_2-CC is best

- Can increase both capacity & efficiency while at the same time reducing all existing traditional emissions plus Hg & CO_2 to near zero
- This is perhaps the only major CO_2 capture & storage application that can make this important claim
- This is quite important as this helps obtain critical public, NGO & environmentalist support required for H_2 infrastructure to develop

Power Generation Will Be Forced to Meet a Disproportionate Share of Any CO_2 Reductions

Transportation fuel users have more votes than CO_2 intensive industries - higher gasoline prices via carbon taxes - no way

Power plants cannot move to China, as other CO_2 intensive industries in Annex 1 nations will, if faced with carbon taxes

Large potential for improved efficiency in power generation

- Improved efficiency usually just reduces CO_2 growth rate; still grows

Large point sources of power gen reduce CO_2 avoidance costs

- Key to addressing the global warming issue is CO_2 capture & storage for new, but especially existing old inefficient coal-fired power plants

CO_2 Mitigation - Existing Coal Power Plants

Over 300,000 MW of existing life expended coal units in U.S.

- Typical unit is >20 years old, paid-off, high emissions & <35% efficient

Strategic grid locations, cheap coal & easy permitting to expand capacity if reduce emissions & increase efficiency

Best options

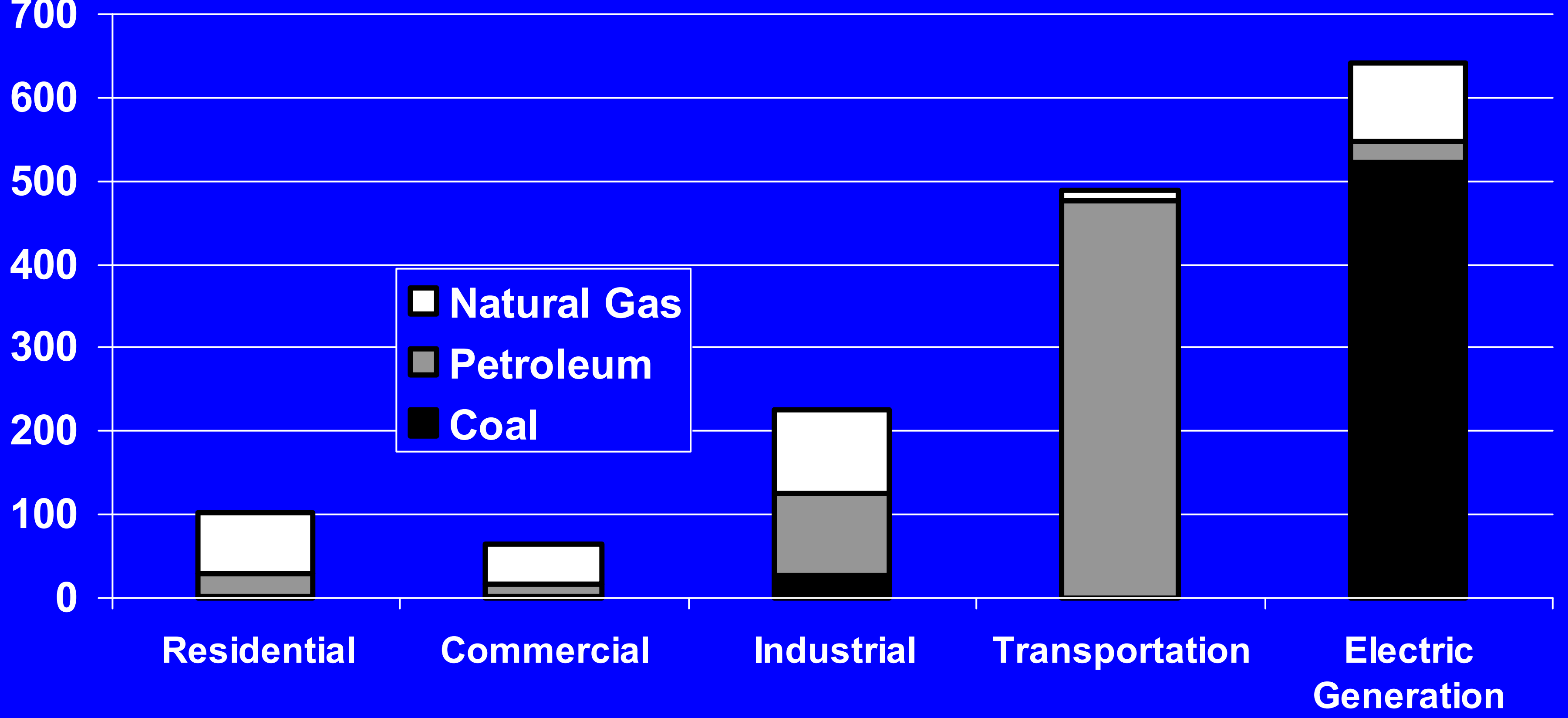
- NGCC repowering (no CO_2 control) if moderate NG prices which is not likely if a carbon constrained world develops in the future
- CGCC repowering with CO_2 capture, especially if nearby EOR or CBM

Gasification repowering increases both capacity & efficiency while reducing all emissions to near zero & staying on coal

- This H_2 based power appears to be one of the best options for massive CO_2 reduction at minimal costs, especially if the CO_2 can be utilized

United States CO_2 Emissions by Sector and Fuels in 2000

Millions of metric tons per year carbon equivalent (x 3.67 for CO_2



Source: U.S. EPA Inventory of Greenhouse Gas Emissions, April 2002

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Status of Gasification for Combined Cycle Power Generation & H_2 + CO_2 Generation

Worldwide commercial gasification capacity

- Almost 50,000 MW_{th} (syngas) operating & growing at 5,000 MW_{th}/yr.
- New projects are mostly petroleum coke or pitch gasification in oil refineries for export power + cogen steam & syngas - polygeneration

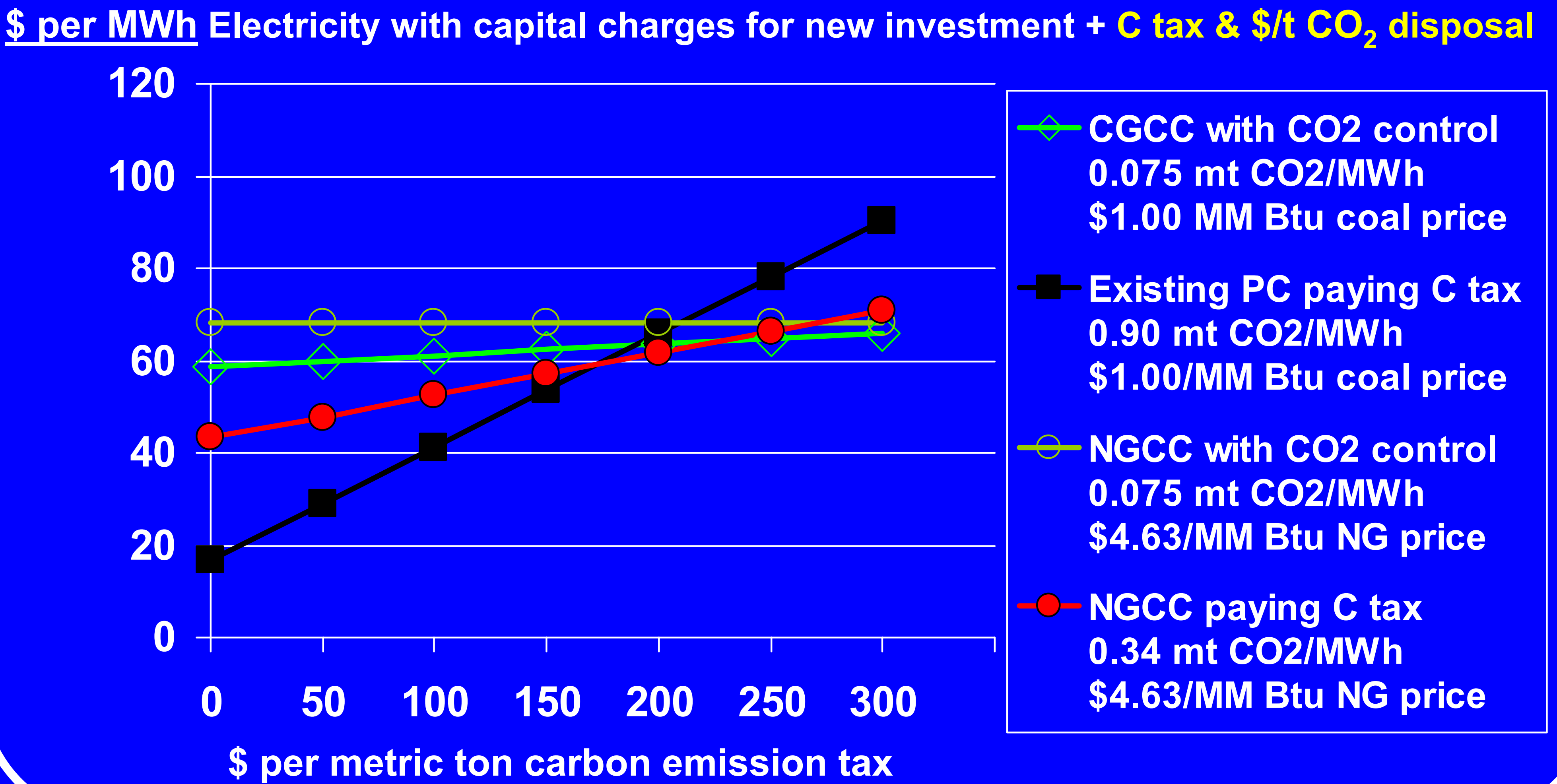
Extensive successful commercial experience with coal & heavy oil gasification producing pure H_2 & CO_2 streams

- Over 15 solid & 40 liquid fuel gasification plants making pure H_2
- Mostly for ammonia fertilizer plus some for oil refinery H_2
- Most are in China, some in USA, Germany, Japan, India & Brazil

General Electric has tested & will give commercial performance guarantees for H_2 fired gas turbines

Farmland in Kansas - Commercial (no subsidies) Coke to H_2 Gasification Plant for Ammonia & CO_2

Electricity Costs for Existing Coal
Moderate Carbon Taxes Have No Impact



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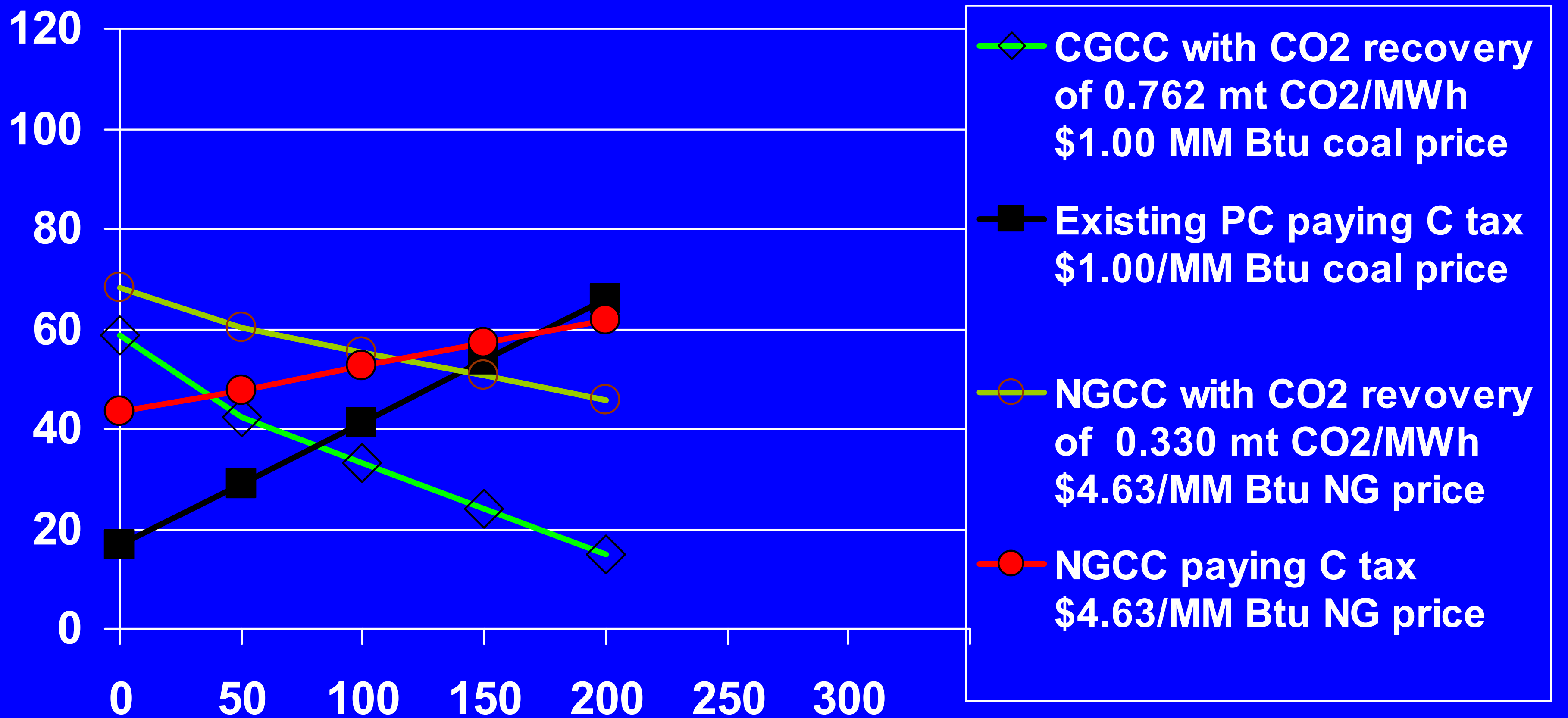
Electricity Costs for Existing Coal Plant Upgrades if Combined CO_2 Recovery Credit & Emission Tax

$ per MWh Electricity with capital charges for new investments & C tax or capture credits



$ per metric ton carbon credit for captured CO_2 & carbon charge for CO_2 emissions

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Hydrogen based Transportation

This is a much bigger challenge than H_2 based electricity

- Requires major changes in existing energy infrastructure & likely delayed until mass production commercialization of fuel cell vehicles
- The "big bang" or ramp-up problem
  - Before the first mass-produced fuel cell vehicles roll off the assembly line, most of the H_2 infrastructure must be in place, faced with poor capital utilization for 10-15 yrs of ramp-up

SFA Pacific recently did a H_2 supply costs scoping study with the final report published July 2002 - NREL/SR-540-32525

- Commercial & near commercial technologies, 8 fuels, 3 H_2 distribution options plus small onsite & large central H_2 production
- Small onsite H_2 suffers from higher energy prices & unit capital costs

Original NETL & IHIG Project Objective

Develop a **consistent & transparent** framework of hydrogen costs for fuel cell transportation applications

Hydrogen costs for various options including:

- 8 Feedstocks - 6 large central, 2 small forecourt & 2 for both
- 5 Conversion Technologies
- 3 Locations
- 2 Size ranges - central H_2 with delivery & fueling vs forecourt H2
- 3 H_2 delivery options from central to forecourt
- 19 cases from this matrix of about 700 possible cases

Utilized commercial technologies as much as possible

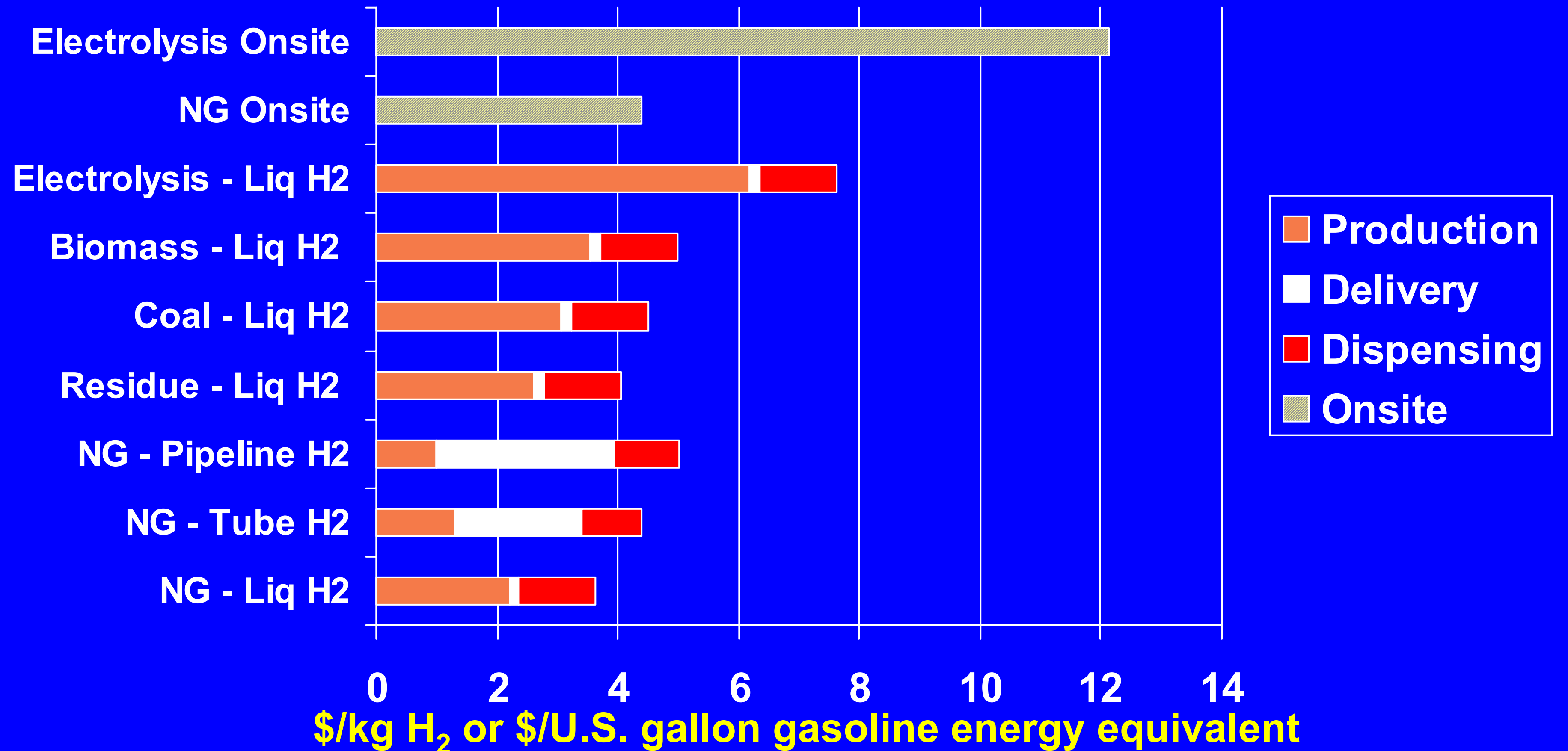
- Only minor step-outs for gasoline reforming & biomass gasification

Hydrogen Economics for Fuel Cell Vehicles

No road tax, 18%/yr capital charges, current technology & energy prices

Central Facility - 60 MM scf/d H2 (200 MW_{th}) design to service 225,000 FC vehicles & supply 411 stations with 329 kg/d per stations

Onsite (Forecourt) - 470 kg/d design to service 550 FC veh & supply 329 kg/d



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Overcoming the "Big Bang" H_2 Ramp-up Issue

The coal gasification H_2 power plant 500 MW_e = 1,000 MW_{th} H_2

- CO_2 capture & storage plus small H_2 liquefaction & liquid H_2 storage tank to fill during lower power demand as H_2 is needed during ramp-up
- Distribute this liquid H_2 to fuel cell vehicle filling stations for the small but growing transportation H_2 requirements, as needed during ramp-up
- Power losses to H_2 are minor & can be easily made-up by other power plants or if peak power problems just add some NG to existing H_2 - CC
- Biomass & wastes are effectively utilized by co-feeding in this large gasification plant wherever they can be delivered at reasonable costs

Would require subsidies to encourage H_2 & CO_2 storage

- Less than currently given renewable power & ethanol in gasoline
- However, this offers much greater social benefits & economic value by creating the essential bridge to the hydrogen economy

Conclusions

- Hydrogen has some inherent problems as it is not an energy source, merely an energy carrier with low energy density
  - Nevertheless, the hydrogen economy is interesting due to unique attributes relative to fuels cells & the global warming issue
- The hydrogen economy favors H_2 from fossil fuel with CO_2 capture & storage as this is cheaper than H_2 from renewables
  - Hydrogen for power generation via coal gasification repowering of old, coal units is the place to start as this avoids infrastructure problems
  - Hydrogen for fuel cell vehicles is a greater challenge due to the "big bang" hydrogen infrastructure & vehicles/fuel ramp-up problems
    - However that can be reduced by extracting hydrogen "as needed" from large hydrogen based coal gasification power plants co-feeding biomass
  - Will require subsidies, however, less than currently given to renewable power & ethanol in gasoline with much greater social benefits