Comparative Economic and Technical Analysis of Power Plants with CO_2 Capture

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by

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Presentation Overview

Background

- SFA Pacific and our CO_2 mitigation work
- The electric utility industry is changing
- Why electric power generation will be forced to meet a disproportional share of any CO_2 reductions

Comparative economic and technical analysis of power plants with CO_2 capture or reduction

- Existing coal-fired power plant retrofits
- Cogeneration & polygeneration
- Status of worldwide gasification as this technology is key to both power plant CO_2 capture & polygeneration

Conclusions

SFA Pacific Background

Basis of name: founded in 1980 as Synthetic Fuels Associates & does extensive work in the Pacific Basin

Perform technical, economic & market assessments for the private industrial sector

Principal work in residual oil upgrading & electric power generation

Niche is objective outside opinion and comparative analysis before companies make major investments

No vested interest in technologies, R&D or project development

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Representative SFA Pacific Clients

UTILITIES	***INDUSTRIALS***	***VENDORS, E&C***
British Gas	BP/Amoco/ARCO	ABB
CEA (Canada)	BHP	Babcock & Wilcox
EdF	Chevron	Black & Veatch
Electrabel	Chinese Petroleum	Bechtel
EPDC (Japan)	Dow/Destec	Cummins
EPRI	DuPont/Conoco	Fluor Daniel
Eskom	ENI	Foster Wheeler
GRI	Exxon/Mobil Oil	GE
National Power	PDVSA	IFP
Power Gen	Saudi Aramco	Kellogg/ Brown & Root
RWE/Rheinbraun	Shell International	Kvaener
Tokyo Electric Power	Statoil	Lurgi
Tokyo Gas	Texaco	MHI
TransAlta	TOTAL/Fina/Elf	Siemens/Westinghouse
Vattenfall	Veba	Weyerhaeuser

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SFA Pacific Background in GHG Issues

World Bank - Efficiency & environmental impact of coal use in China

United Nations - Several energy & environmental projects/conferences

China - International consultant to the People's Republic of China National Response Strategy for Global Climate Change

Global Environmental Facility (GEF) - Recommendations & suggestions on coal technologies in a carbon constrained world

U.S. DOE

- Review of policy & energy technology sections of 1995 IPCC draft
- Objective analysis of CO_2 control options for electric power generation (see our 3 papers for the GHGT-4 & GHGT-5 conferences)

Several major private client analyses

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Kyoto Protocol Has Several Fatal Flaws

Ignores developing nations - most of the world's CO_2 growth

- Requires simple, fair & transparent Joint Implementation, Clean Development Mechanism & CO_2 emission trading. However, vested interests want subsidies, not simple, fair & transparent systems

Most CO_2 reduction burden on U.S. - 26% reduction from 2000

- Highly unlikely that the U.S. will ratify - "It's the economy, stupid"
- See the October 1998 EIA Kyoto Report to Congress - SR/OIAF/98-03

"Leakage" would likely increase CO_2 growth by economically forcing CO_2 intensive industries in Annex I nations to move production to cheaper but less efficient & coal-based developing nations like China

- Globalization & free trade forces companies to be cost competitive
- Governments cannot force companies to stay & be non-competitive

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Fundamental Changes in Power Generation

Deregulation, increased competition & globalization

- Restructuring: takeovers, asset resales & upgrades to create large, more economically efficient Genco, Transco & Disco systems
- Convergence of power, gas & oil industries into large more cost & fuel efficient power generators (Genco)
- ISO or RTO of transmission (Transco) to assure system reliability
- Time of day rates (both buying & selling) & distributed generation to improve distribution (Disco) as well as overall system utilization

Uncertainties in all areas of power generation

- Applications, markets, technology & prices
- Feedstocks: options, availability & price
- Environmental requirements have an increasing impact with CO_2 reduction & sequestration being the greatest long term challenge

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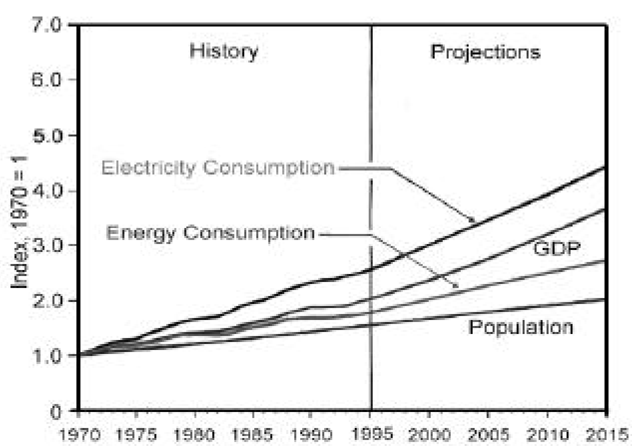
World Energy, GDP & Population Trends

Clearly Show Electricity is the Energy of the Future



Source: 1997 US DOE/EIA International Energy Outlook

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

Environmental hypocrites driving urban assault vehicles (SUVs) have more votes than CO_2 intensive industries

Power plants can not move to China, as many CO_2 intensive industries in Annex I nations will, if faced with carbon taxes

Large potential for cost & efficiency improvements in power generation thanks to deregulation

- **However, this only reduces the rate of CO_2 growth, few reductions**

Ultimately must face up to CO_2 reduction & CO_2 sequestration

- **Largest point sources of CO_2 are coal-fired power plants**
- **Replace coal with NG, renewables & waste fuels where economical**
- **However, fossil fuels with CO_2 sequestration will likely be required**

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CO_2 Retrofit of Existing Coal Power Plants

Background

- **Existing pulverized coal (PC) boiler power plants generate over 45% of the total annual power in North America (over 55% in the U.S.)**
- **They have the highest CO_2 emissions yet the lowest power costs**
- **Low cost due to paid-off facilities, low operating cost & emissions "grandfathering" (not required to meet same emissions as new units)**

Advantages to CO_2 retrofit of existing PC power plants

- **Location, location, location**
- **Existing power & fuel transportation & handling infrastructures**
- **Ease of permitting as any major retrofit greatly reduces <u>all</u> emissions**
- **Potential to greatly up-rate capacity at these existing sites**

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TransAlta

An innovative & forward thinking company that began as an investor-owned regulated electric utility in Western Canada

Now an international power generator

- Numerous NGCC cogeneration IPPs in Canada & New Zealand
- Industrial cogeneration at the large Tar Sands upgrader facilities
- Large existing PC power plants in Canada & the United States

One of the few electric power generators that is objectively addressing & economically analyzing the GHG issue

- See GHG section of the TransAlta web site at www.transalta.com
- Funded two analyses of CO_2 recovery for existing PC power plants
  - Flue gas amine scrubber by Fluor Daniel
  - O_2 combustion with flue gas recycle by ABB (CE & Lummus)

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Comparative Analysis of CO_2 Capture

SFA Pacific had already developed a simple & transparent analysis to compare CO_2 options for <u>new</u> power plants

- See 1998 GHGT-4 paper
- Based on single page spreadsheet for each option showing:
  - Principal energy & material balance in just MW_e, MW_{th} & mt/h
  - Capital cost build-up for all key processes via consistent unit costs
  - Costs of electricity & CO_2 avoidance via consistent economic inputs
  - Baseline is power cost & CO_2 emissions of a new state-or-the-art NGCC

TransAlta analysis presented an opportunity to modify the SFA Pacific analysis for <u>existing</u> power plant CO_2 options

- Table 1 in GHGT-5 retrofit paper is an example of the single page spreadsheet modified for an existing coal power plant CO_2 retrofit

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Existing Coal Power Plant CO_2 Retrofit Options

Conversion to lower carbon fuels without CO_2 recovery

- Natural gas - new NGCC & NG-GT repowering
- Biomass/coal co-firing - 10% of PC feed & 50% via biomass gasifier
- More efficient coal use via CGCC-coal gasification combined cycle

Conversion with CO_2 recovery technologies

- PC retrofits for TransAlta work: flue gas scrubber & O2 combustion
- H_2-fired CC via NG & coal gasification - CO_2 scrubbed from HP H_2
- Included H_2-CGCC & PC flue gas scrubber for 65% CO_2 reduction so same CO_2 emissions as a new NGCC without CO_2 recovery

Conversion to no net CO_2 emissions technologies

- Biomass GCC, nuclear & wind turbines

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Basis for Comparing CO_2 Retrofit Options

Complexities of comparing existing power plant CO_2 retrofits

- Baseline power cost & emissions - old PC or new NGCC - as this has a major impact on both the power & CO_2 emissions avoidance costs
- Handling of old existing PC investment that is not yet fully amortized (paid-off) versus the new retrofit investment
- Handling loss of efficiency & capacity due to CO_2 recovery retrofit

Basis chosen to assure the most objective comparison

- Used existing PC power plant as baseline for costs & emissions; thereby low power costs but at high CO_2 emissions per MWh
- Refinanced any remaining old capital with the new retrofit capital
- CO_2 & O_2 production included in power plant costs & internal power + new NGCC capacity as required to maintain original net capacity
- No renewable subsidies or credits for other PC emission reductions

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Coal Power Plant CO_2 Retrofit Results

See Table 2 of GHGT-5 retrofit paper for summary of results

Continued coal use <u>with</u> CO_2 recovery retrofit is favored <u>if</u> the high pressure CO_2 obtains a slight byproduct credit

- Current & future potential uses include enhanced oil recovery (EOR) & coal bed methane (CBM) recovery

<u>If</u> the CO_2 is a disposal cost, replacement with a new NGCC <u>without</u> CO_2 recovery is favored over coal <u>with</u> CO_2 recovery until NG prices reach about $6 per million Btu

Co-firing NG or biomass with coal has low costs but only moderate CO_2 reductions

- Favors NG-GT repowering due to efficiency & capacity gain while maintaining the coal option for the future via CGCC or H_2-CGCC

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Proposed CO_2 Sequestration Projects That Reduce Costs Via Slight Byproduct Value

Dakota Gasification - CO_2 recovery from <u>existing</u> <u>coal</u> gasification SNG for enhanced oil recovery (EOR) in Canada

Shell Oil Pernis Refinery - CO_2 recovery from <u>existing</u> <u>residual</u> oil gasification polygeneration for use in greenhouses

China - CO_2 recovery from <u>existing</u> <u>coal</u> gasification ammonia for deep un-mineable coal bed methane (CBM) recovery

Alberta, Canada - CO_2 recovery from <u>existing</u> <u>coal</u> power plant for improved tar sands EOR

BP/Amoco & ARCO Alaska North Slope - CO_2 recovery from <u>existing</u> gas turbines or others sources for improved EOR

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Coal Power Plant CO_2 Retrofit Results

Of the CO_2 recovery options H_2-CGCC has advantages over both PC retrofit flue gas scrubber or O_2 combustion

- PC retrofits reduce both capacity & efficiency by about a third where as new H_2-CGCC @ same $/kW increases both capacity & efficiency
- O_2 combustion requires 4.5 times more O_2 per net MW coal capacity

The 65% CO_2 recovery option with coal (same as new NGCC) helped the PC retrofit flue gas scrubber option the most

The renewables & nuclear options have limitations

- Nuclear: high costs, decommissioning, waste & liability issues
- Wind turbines: low annual load factor & required backup generation
- Biomass: high costs, supply & land limitations & transportation cost
  - At only $500/ha/yr gross costs / 5 mt carbon/ha/yr = $100/mt carbon in-field plus transportation & utilization costs + 340 hectares per MW

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Coal Power Plant CO_2 Retrofit Conclusions

CO_2 capture for existing coal-fired power plants must be included in any objective analysis of CO_2 mitigation options

- Key issue: can high pressure CO_2 find a small byproduct value
- CO_2 byproduct markets already exist & are growing for EOR & CBM
- Should favor this option in areas of coal power plants, EOR & CBM

Large potential for CO_2 capture technology improvements

- This analysis only included commercial technologies
- Best opportunities appear to be gasification, CO_2 scrubbers (both LP flue gas & HP syngas), air separation, gas turbines & fuel cells
- Also good opportunities for improvements in technology integration

The single page spreadsheet analysis facilitates objective identification & comparison of various CO_2 options

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Cogeneration & Polygeneration

Background

- The SFA Pacific single page spreadsheet comparative technical & economic analysis of CO_2 mitigation options began with a focus on traditional central power plants
- This makes the analysis & comparisons easy to understand

However, the ongoing deregulation of electric utilities is fundamentally changing the future of power generation

- Allows non-utility generators to sell power to the grid at a fair price
- This gives cogeneration key advantages over central power plants
- Sales of cogen power to the grid also favors the use of gas turbines
- Strong growth of cogeneration in nations that have deregulated

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Large Cogeneration Potential

The European cogen experience clearly shows there is significantly more cogen potential than many believed

- The Netherlands is delaying large cogen projects due to excess power
- New cogen application like gas turbine exhaust for crude oil heaters

There is still large potential for additional cogen in North America once full deregulation & baseload power is needed

- Expect "PURPA-2" type cogen incentives or efficiency tax credits

The Japanese Gas Association 1991 Industrial Repowering Analysis showed big potential (17,500 MW_e), large power efficiency gain (16%), & major CO_2 reduction (50 MM t/yr)

Major cogen opportunities in China once power is deregulated

- 60% of China's total coal use is <u>not</u> used in central power plants

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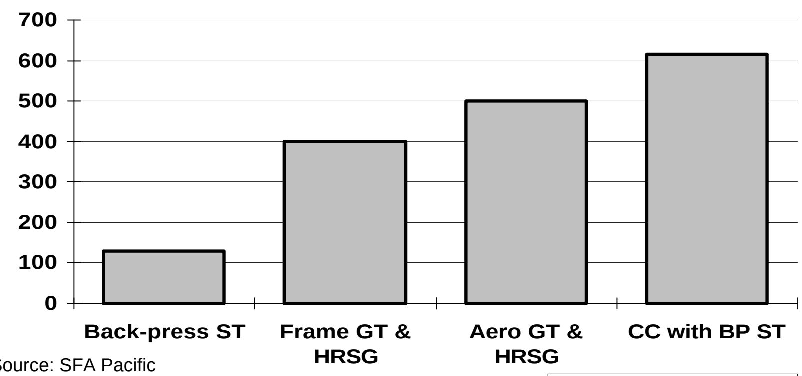
Maximum Power in Total Cogeneration Clearly Favors Gas Turbines Over Steam Turbines

For a given heat host, 5 times more power with GT vs ST
This is the key issue as true cogeneration is heat host limited

Power-to-Steam ratio: kWe per t/hr cogen 10 bar steam (no steam to condenser)



Source: SFA Pacific

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Baseline for Cogeneration Analysis

See Table 1 of GHGT-5 update of new power plant paper

New "state-of-the-art" NGCC central power plant - 400 MW_e

New natural gas industrial boiler - 342 MW_{th} or 614 mt/h steam

- This size matches the NGCC heat recovery steam generator (HRSG)
- Medium pressure steam typical of industrial requirements

Estimated capital cost, efficiency & CO_2 emission

- For each (NGCC power & NG boiler steam) plus total of both

Estimated annual revenue requirements & product costs

- For each (NGCC power & NG boiler steam) plus total of both
- Identical price of natural gas & capital recovery factor

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Cogeneration Results

See Table 1 of GHGT-5 update of new power plant paper

- Assumed identical power & steam rates to “keep it simple”
- Assumed the same economic inputs to keep it fair
- Conservative cogen design making MP (not LP) steam plus the extra capital cost to convert all this cogen steam into power for flexibility

Cogeneration reduced CO_2 emissions by 24% while at the same time reducing total capital & revenue requirements

- This creates a negative cost of CO_2 avoidance

Assuming steam value at only 75% of industrial boiler estimate still reduced the power costs from 3.6 to 3.1 cents per kWh

- 10 atm. MP steam value in cogen was only $6.90 per mt

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Two Additional Cogeneration Options

Smaller cogeneration for commercial applications

- 1.0 MW_e & 1.0 MW_{th} of hot or cold water for space heating/cooling
- Based on NG-fired reciprocating engine (RE) with hot water heat recovery & bromine absorption refrigeration cooling
- High power-to-heat ratio & operating flexibility favor RE
- All commercially proven technology

Larger industrial polygeneration application

- 400 MW_e + 400 MW_{th} steam + 400 MW_{th} methanol (1,732 mt/d)
- Based on coal gasification to generate clean synthesis gas for once-through slurry-phase MeOH followed by gas turbine cogen
- All commercially proven technology

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Small Cogen & Large Polygeneration Results

Same positive results as the NGCC cogeneration

However, the baseline assumptions are more debatable

- Small cogen alternative baseline could be a lower unit cost NGCC based power for the grid plus an electric heat pump
- Large coal-based polygeneration alternative baseline could be NGCC & NG-based MeOH, thereby much lower CO_2 /MWh_e baseline

Nevertheless, both have efficiency advantages that are enhanced by CO_2 concerns & deregulation of power gen.

Gasification polygeneration is also synergistic with H_2, once-through liquid phase DME & F-T as well as CO_2 recovery

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What is Polygeneration

Defined as gasification to make synthesis gas (H_2 & CO) for GT-based cogen steam/power + syngas chemicals & fuels

Shell Pernis refinery project is a good example, no subsidies

- Pitch gasification - 3 units (if all 3 to GCC power about 400 MW_e)
- However, two gasifiers for refinery H_2 & third gasifier for GCC cogen with 2 GE 6B's (115 MW_e + refinery steam) with NG back-up

Great potential for polygeneration in the future due to ongoing deregulation of all energy sectors, but especially power gen.

- Use of low value "opportunity fuels" high in metals, nitrogen & sulfur
- Offers greater flexibility than traditional power plant relative to fuels, products, revenues, emissions, efficiency & annual capacity factors
- Even attractive for CO_2 recovery (will likely add this to Pernis)

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Gasification

Gasification is simple & commercially well proven technology

Gasification is traditionally used for manufacture of synthesis gas (H_2 & CO) for chemicals such as ammonia fertilizer

New gasification applications are emerging due to:

- **Growth & deregulation of electric power generation**
- **Improved gas turbines**
- **Stringent emissions mandates (air & solid wastes)**

A database of "real" gasification projects is a powerful tool to assess the role of gasification in current & future markets

- **Developed by SFA Pacific with financial support of U.S. DOE & technical support of the Gasification Technology Council members**

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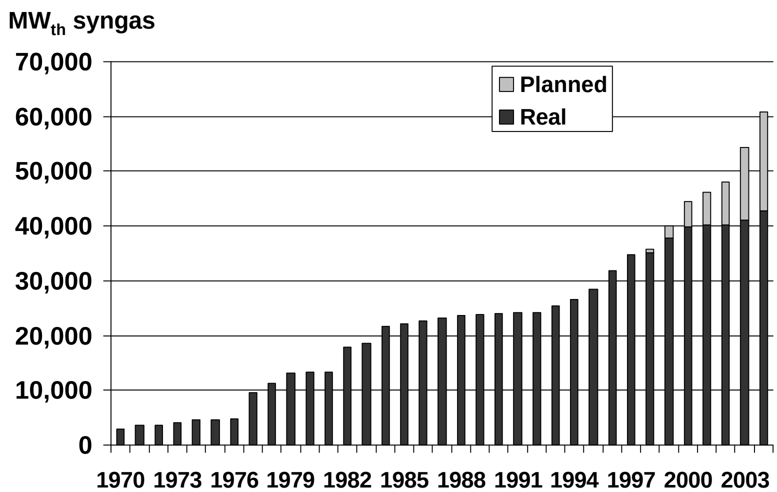
Cumulative Worldwide Gasification Capacity in MW_{th} Synthesis Gas Output



Source: SFA Pacific, Inc. for the U.S. Department of Energy

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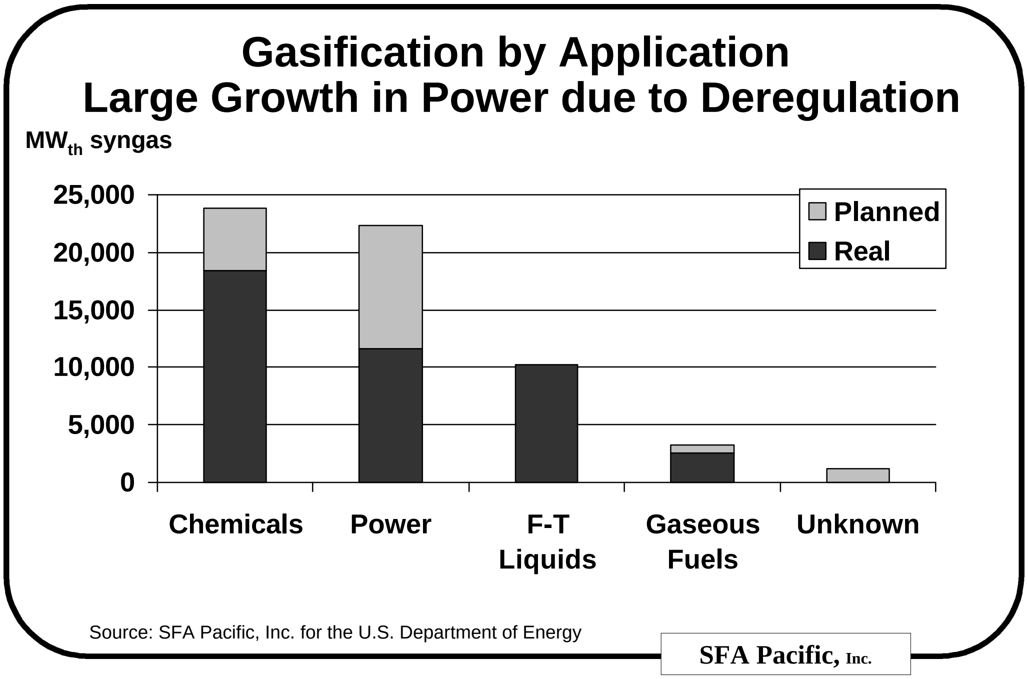

Gasification by Application
Large Growth in Power due to Deregulation
MW$_{th}$ syngas
25,000
20,000
15,000
10,000
5,000
0
Planned
Real
Chemicals
Power
F-T Liquids
Gaseous Fuels
Unknown
Source: SFA Pacific, Inc. for the U.S. Department of Energy
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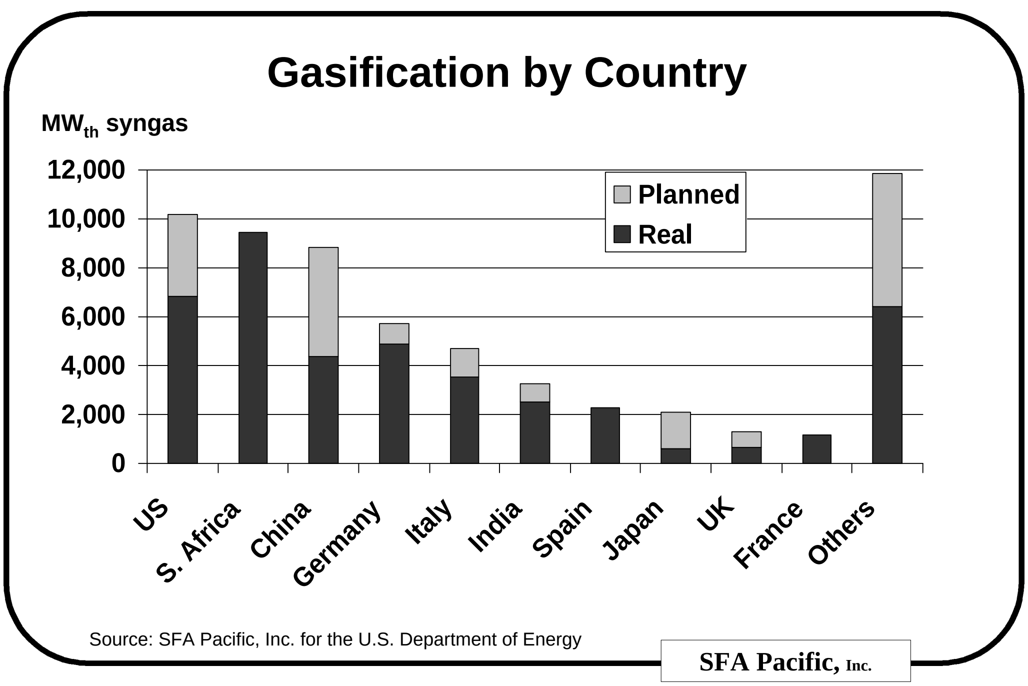

Gasification by Country
MW$_{th}$ syngas
12,000
10,000
8,000
6,000
4,000
2,000
0
Planned
Real
US
S. Africa
China
Germany
Italy
India
Spain
Japan
UK
France
Others
Source: SFA Pacific, Inc. for the U.S. Department of Energy
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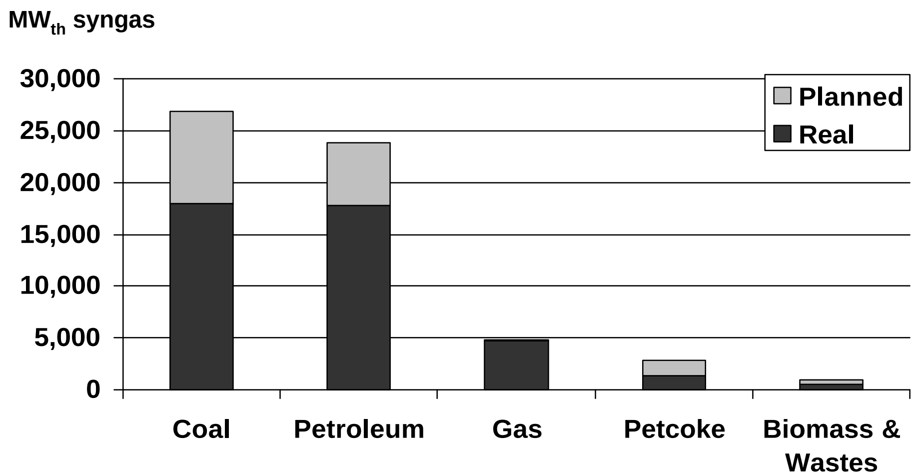
Gasification by Primary Feedstock



Source: SFA Pacific, Inc. for the U.S. Department of Energy

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Top 10 Real Commercial Gasification Projects

Plants	Location	Gasifiers	MW$_{th}$ syngas	Year	Feedstock/Products
Sasol-II	S. Africa	Lurgi	4,130	1977	coal / F-T liquids
Sasol-III	S. Africa	Lurgi	4,130	1982	coal / F-T liquids
Repsol	Spain	Texaco	1,654	2004	residue / electric
Dakota	USA	Lurgi	1,545	1984	lignite / SNG
SARLUX	Italy	Texaco	1,067	2000	residue / electric
Shell MDS	Malaysia	Shell	1,032	1993	NG / F-T liquids
Linde	Germany	Shell	984	1997	residue / H_2&MeOH
ISAB	Italy	Texaco	982	1999	residue / electric
Sasol-I	S. Africa	Lurgi	911	1955	coal / F-T liquids
Total/EdF/ Texaco	France	Texaco	895	2003	residue / electric

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Gasification Projects without Subsidies

Chemicals from coal or pet coke	MW_{th} syngas
• Ube Ammonia - Japan	295
• Farmland - Kansas, USA	295
• Eastman Chemicals - Tennessee, USA	190
Refinery polygeneration from pitch or coke	
• Repsol - Spain	1,545
• Total/EdF/Texaco - France	895
• Exxon - Texas, USA & Singapore	800
• Shell - the Netherlands	637
• Nippon Oil - Japan	620
• Motiva - Delaware, USA	588

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Driving Forces for Gasification

The facts clearly show that gasification is alive & well

- Annual growth of about 3,000 MW_{th} syngas or 7% of total capacity

Fuel of choice for new projects are "opportunity fuels"

- Usually higher in sulfur & heavy metals than coal
- Many have lower capital & feedstock costs than coal

Current surge in gasification projects is in electric power applications in countries with electric power deregulation

- Gasification enables gas turbine based cogeneration at much higher power-to-cogen heat ratio than possible with steam systems
- Polygeneration offers technical, economic, environmental & efficiency advantages that are impossible in a central power plant

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Conclusions

Electric power generation will be forced to meet a disproportionate share of any CO_2 reductions

- Both new & existing power generation facilities must be addressed

Large potential for lower costs & higher efficiency in new power generation facilities <u>after</u> deregulation

- Favors cogeneration & polygeneration over new central power plants
- Cogeneration & polygeneration in China & India are essential, however, this is not in the best interest of regulated utilities
- However, cogeneration generally just reduces the rate of CO_2 growth

Ultimately must face up to CO_2 reduction & CO_2 sequestration

- Replace coal with NG, renewables & waste fuels where economical
- However, these options are limited & renewables appear over-sold

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Conclusions

Must objectively consider fossil fuels with CO_2 sequestration

Retrofit of existing coal plants with CO_2 recovery appears competitive with replacement by NG, renewables or nuclear

- Key issues are future natural gas prices & the cost reductions <u>if</u> high pressure can CO_2 obtain a small byproduct value for EOR or CMB
- Gasification rebuilds can greatly increase the capacity, efficiency & environmental performance of existing coal power plants

Gasification based polygeneration plants are currently being built at commercial scale without subsidies

- Polygeneration has the unique advantage of also recovering CO_2 at potentially low incremental costs

Many opportunities for technical & economic improvements

- However, requires objective & transparent comparative analysis

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