Present Status and Future of Coal Gasification Projects in Korea

2014. 9. 1.

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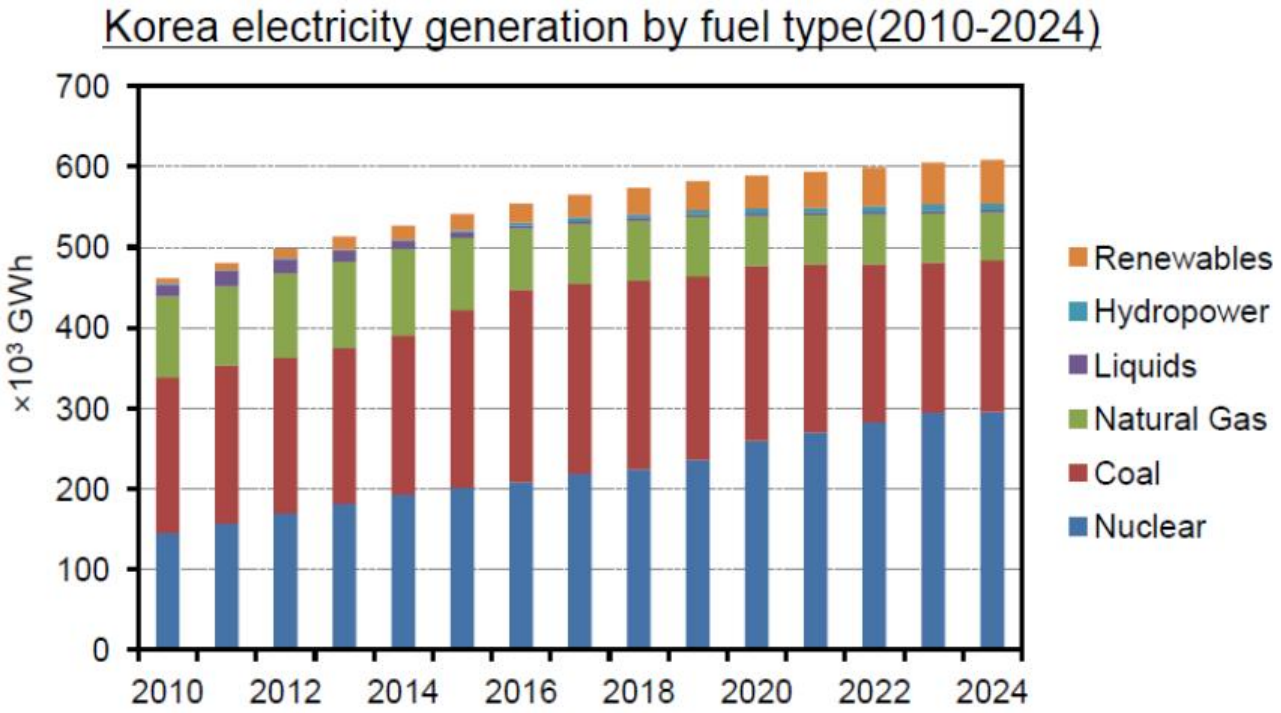
Contents

Importance of Coal in Korea's Electricity Generation



- Coal consumption outlook for Korea electricity generation : from 42% in 2010 to 31% by 2024.
- It is important for Korea, a country lacking in natural resources, to build up an optimal mix of energy sources by introducing new thermal power generation systems using coal.
- In addition, High-efficiency coal-fired power generation technologies are essential to secure energy and prevent global warming simultaneously.

Source: Yong Tack Kim, "Overview of IGCC Demonstration Project in Korea," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

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Korea's Electricity Generation by Energy Source

Energy Source		Nuclear	Coal	LNG	Petroleum	Hydro	New/ Renewable	Sum
Installed Capacity (MW, %)	2002	15,716 (29.2)	15,931 (29.6)	13,618 (25.3)	4,660 (8.7)	2,300 (4.3)	1,576 (2.9)	53,801 (100)
	2012	20,716 (25.3)	25,128 (30.7)	21,885 (26.8)	5,293 (6.5)	4,700 (5.7)	4,084 (5.0)	81,806 (100)
Actual Electricity Generation (GWh, %)	2002	119,103 (38.9)	118,022 (38.5)	38,943 (12.7)	25,095 (8.2)	2,078 (0.7)	3,233 (1.1)	306,474 (100)
	2012	150,623 (29.6)	200,482 (39.4)	126,358 (24.9)	15,610 (3.1)	3,675 (0.7)	11,632 (2.3)	508,380 (100)

- 38-39% of electricity is produced by coal-fired power plants in Korea.
- Increased dependence on coal with diminished Nuclear power.

- Importance of clean coal technologies has increased for higher efficiency, reducing CO_2.
- Need technologies for using more low-grade coals.

Table Source: "6th Basic Plan for Electricity Supply and Demand," MOCIE, 2013. 2.

Background of Starting IGCC in Korea

- Needs for reducing greenhouse gas emissions against global warming
  - ✓ Target for reduction of greenhouse gas emissions
    by 30% against forecast for year 2020
    by 4% reduced compared record of year 2005
  - ✓ 26.7% reduction in electric power industry
  - ✓ IGCC Technology is suitable for capture CO_2 (Pressure ↑, WGS)
- Achievement government policy goal for promoting new and renewable energy use in electric power generation from 2% in 2012 up to 10% by 2022(Mandatory Mission)
  - ✓ IGCC is regarded into new energy in Korea
    ※ RPS : **R**enewable **P**ortfolio **S**tandard

Year	`12	`13	`14	`15	`16	`17	`18	`19	`20	`21	`22
%	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0

- Achievement of the goal of constructing 300MW IGCC Demo plant by 2015 according to "*Korea Electric Power Development Basic Plan(2010-2024)*"

Source: Y. T. Kim, "Overview of IGCC Demonstration Project in Korea," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

Background for Applying Gasification for Coal Power Plants

Key Words :

- High Efficiency: Due to increase in Gas Turbine efficiency
- Poly-generation: Power + Synthetic fuel + Hydrogen + Chemicals
- CO_2: Favorable in capture
- Low-rank coal: Large reserve, Low price
- Disadvantages: High captital cost, Low availability

(World IGCC Capacity Estimation (2007-2030)

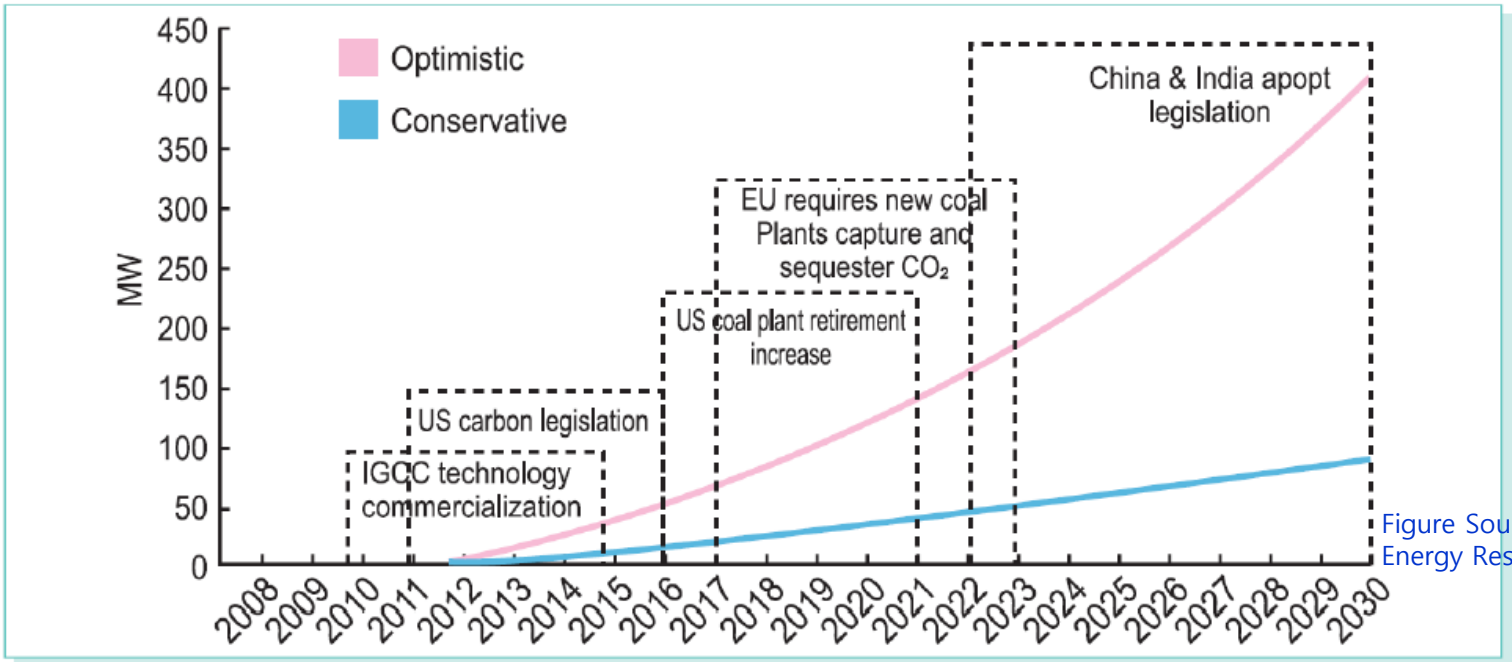
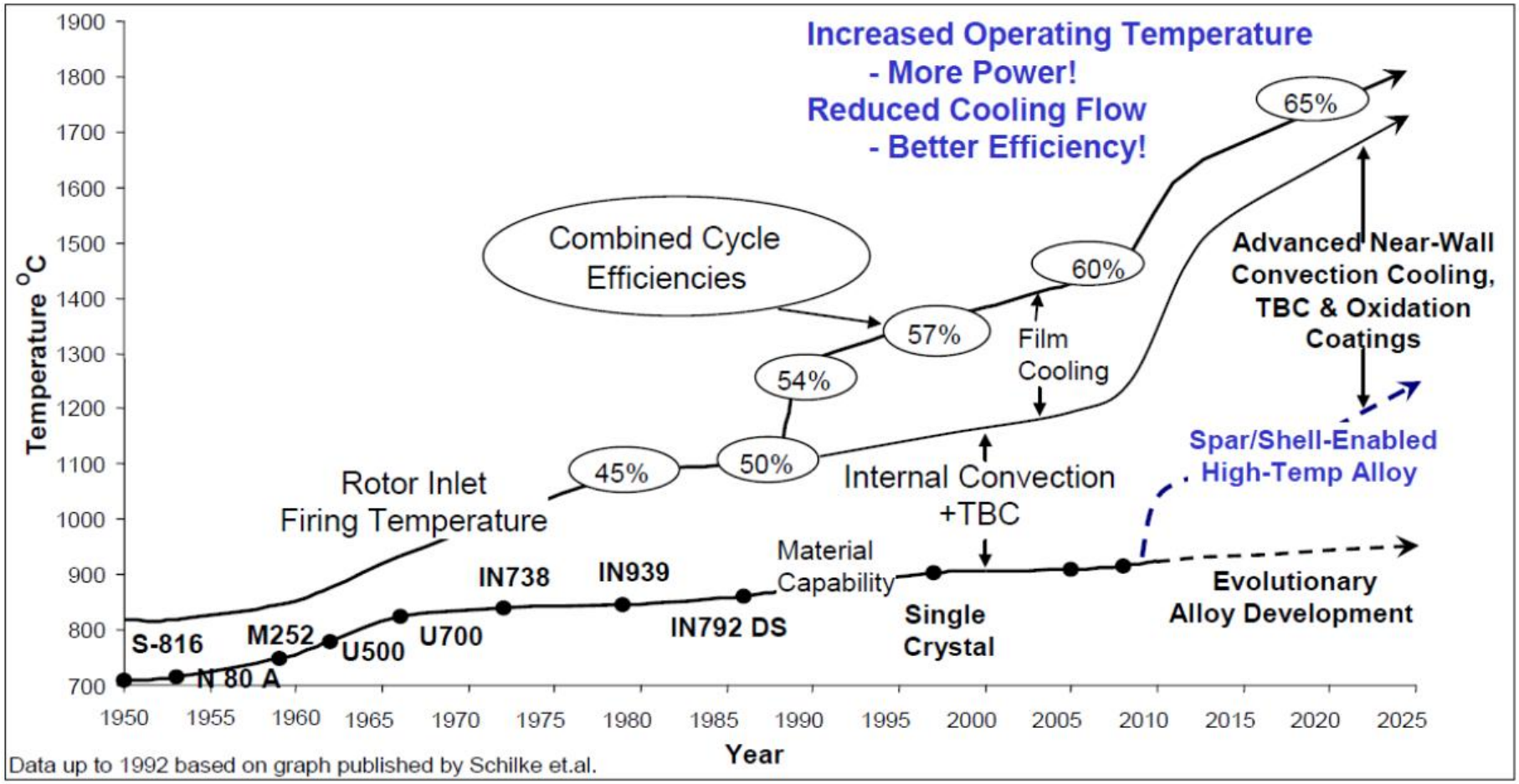


Figure Source: Emerging Energy Research, 2007.

Background : Increase in IGCC Efficiency by Gas Turbine Technology

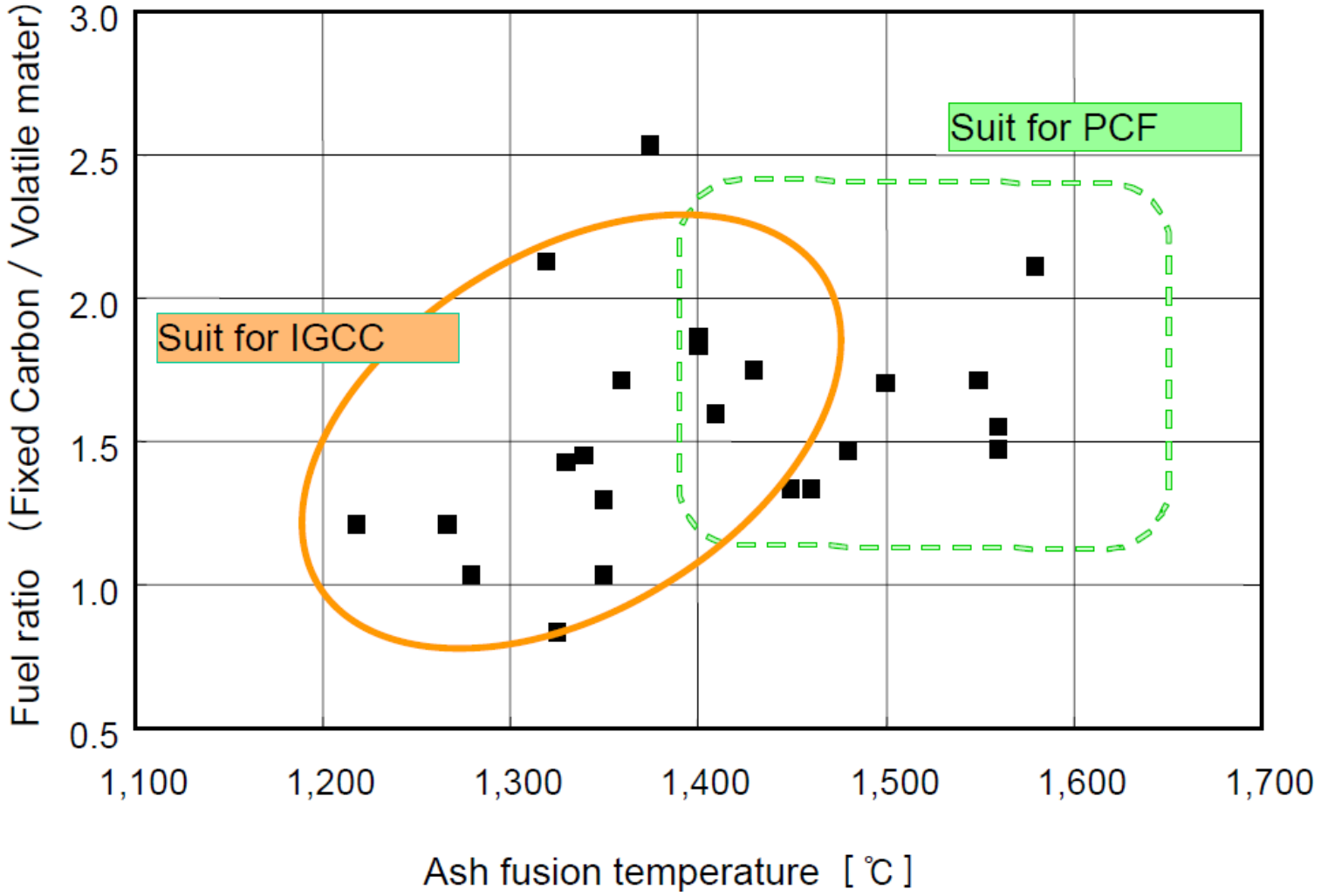
- IGCC : Combined Cycle (Gs Turbine + Steam Turbine)
- Conventional Coal Power Plants : Only Steam turbine



Source: Richard A. Dennis, "H2 Turbines for Clean, Efficient, CCS Power Systems," NETL, NASA Glenn, Cleveland, OH Green Forum, 2009/9/22.

Background : IGCC is More Suitable for Low Rank Coals

- Low ash fusion coals like Indonesian low rank coals → More suitable for IGCC application



Source: Tetsuji Asano, 'Progress in Japanese Air-blown IGCC Demonstration Project Update,' Coal Gasification Symposium, Jeju, Korea, 2012/04/26.

Definition of New & Renewable Energy in Korea

	Energy Source		IEA	EU	USA	JAPAN	CHINA	KOREA	AUSTRALIA	FRANCE	S. AFRICA	UK
Renewable Energy	Hydro	Large Hydro	○	×	○	×	○	○	○	○	○	○
		Small Hydro	○	○	○	○	○	○	○	○	○	○
		Pumped Storage Power Generation	×	×	×			×				
	Geothermal	Power Generation	○	○	○	×	○	○	○	○		
		Heat Pump	×	×	×	○						
	Solar Energy	Photovoltaic	○	○	○	◎	◎	◎	○	○	○	○
		Solar Heating	○	○	○	○	○	○		○		
		Solar Heat Electricity Generation	○	○	○		○	○	○		○	
		Passive Solar	×	○	×	○	○	×				
	Sea Power		○	○	○	×	○	○	○		○	○
	Wind Power		○	◎	○	○	◎	◎	○		○	○
	Biomass	Solid Biomass	○	○	○	○	○	○	○	○	○	○
		Biomass Gas	○	○	○	○	○	○	○	○	○	○
		Liquid Biomass	○	○	○		○	○		○		
		Black Liquor				○		×	○			
	Wastes	Renewable Municipal Wastes	○	○	○	○		○	○	○	○	○
		Non-renewable Municipal Wastes	×	×	×	○		○				○
		Industrial Wastes	×	×		○		○				○
		Non-specific Combustible Renewables	×	×		○		○				○
		Waste Heat from Wastes	×	×		○		○				○
		Food Wastes				○		×	○			
	Temperature Difference Energy		○	○	×	○		×				
New Energy	Fuel Cell							◎				
	Gasification/Liquefaction of Coal							○				
	Hydrogen				○			○				

RPS Weighting factor for New/Renewable Energy in Korea

Only applicable for electricity, not for steam.

Weighting Factor	Energy Source
0.25	IGCC, Process Waste Gas
0.5	Wastes Land Filled Gas
1.0	RDF dedicated electricity generation Wastes Gasification Electricity Generation Bio-energy Hydro Tidal (with Tide Embankment) Wind Power (Land-based)
1.5	Woody Biomass Dedicated Electricity Generation Wind Power (Sea-based, < 5 km from land)
2.0	Fuel Cell Wind Power (Sea-based, > 5 km from land) Tidal (w/o Tide Embankment)

RPS (Renewable Portfolio Standard)

Effect of RPS Obligation to Power Generation in Korea

❑ **Electricity generation capacity jumps till '22 → Gradual increase in RPS obligation amount.**

- RPS supply obligation amount increases about 15 times for the next 10 years.

Item / Year	'12	'13	'14	'15	'16	'17	'18	' 19	'20	'21	'22
Base Electricity Amount (GWh)	54,336	58,209	53,303	53,410	52,942	58,728	70,382	72,706	74,651	72,783	72,783
RPS Supply Obligation (%)	1.4	1.96	3	3.9	4.7	6.6	8.2	9.6	11.3	13.4	15.3
Obligation Amount(GWh)	760	1,140	1,599	2,083	2,488	3,876	5,771	6,980	8,435	9,753	11,135

❑ **Various risk in company to comply RPS obligation**

- Penalty when not-fulfilling the RPS obligation and REC(Renewable Energy Certificate) purchasing
- Limited space, fund, NIMBY, permits for installation
- Difficulty in securing stable biomass fuel supply (Cost, Quantity, Supply period)
- Securing economical margin (Plant capacity, Construction cost, Operating cost)

❑ **Every power generation companies prefer biomass co-firing which is an accomplishable method in a short time.**

- Wood pellet, Wood chip, Organic solid fuel, RDF, Process waste gas, Bio-coal, etc.

Source: Y. Yun, "Electricity Generation Using Biomass by Dedicated & Co-firing System in Korea," Bioenergy Korea Conf. 2013 Int. Symposum, 2013/11.

Korea IGCC Project – Overview

Title	" Self-Reliance of Design Technology and Construction for 300MW Class IGCC Demonstration Plant to Secure Korea IGCC Technology "
Consortium Partners	➢ Contractor : - KOWEPO, DHI, HHI - Institutes (KIER, IAE) - Universities (10) - Engineering & Construction Company, Gencos
Period	➢ 1st phase : 2006.12 ~ 2010. 4 (Finished) ➢ 2nd phase : 2011.02 ~ 2016.11 (70 months)
Budget	➢ Total : 1.4 Billion US$ - Government Subsidy : 0.1 Billion US$ (9%) - Partners Contribution : 1.3 Billion US$ (91%)

Source: Y. T. Kim, "Overview of IGCC Demonstration Project in Korea," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

Specification of Taean IGCC

Division		Characteristics		Remark
Power Output		Gross	Net	GT : 235 MW ST : 145 MW (Base : HHV)
		380 MW	300 MW	
Feed Stock		Subbit. ~ bit.coal (Ignition fuel : LNG)		Moisture : ≤ 25% HHV : ≥ 5,242kcal/kg
Whole IGCC Plant Efficiency		Net 42%		Base: HHV
Gasification Plant	Efficiency	93.46%(Design)		-
	Syngas Heat Output	546 Gcal/hr		-
Availability		Over 85 %		Whole IGCC plant
Coal Flow		2,670 ton/day		As received basis
Air Pollutant Emission		SOx : < 15ppm NOx : < 30ppm Dust : < 3㎎/S㎥		@15% O_2

Plant Area : 81,320㎡

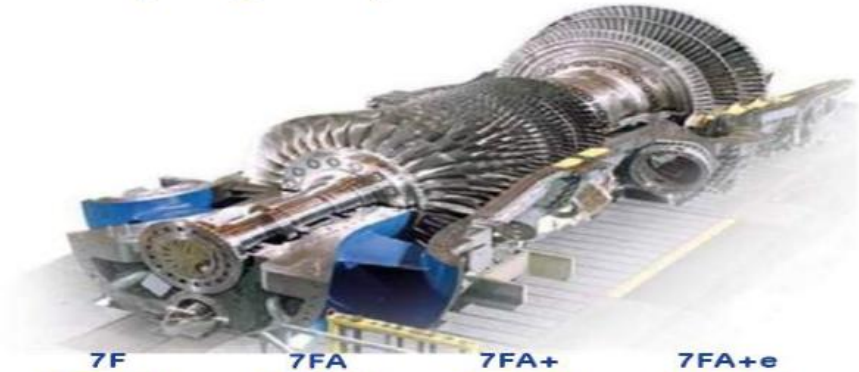
Source: Y. T. Kim, "Overview of IGCC Demonstration Project in Korea," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

Construction Site View – Taean IGCC (2014/03)

G/T Specification – Taean IGCC

GE Gas Turbine

7F Syngas product evolution



7FSyngas gas turbine
- Increased firing temperature
- Increased pressure ratio
- Select hot gas path component redesign for syngas operations

Difference from 7FB NG
- MNQC combustor
- Large area back end to accommodate increased mass flow
- Syngas fuel skid and piping

Items	GT		ST		Combined	
Efficiency (HHV, %)	Gross	Net	Gross	Net	Gross	Net
	37.66	37.58	38.45	36.84	54.23	53.29

ASU Specification – Taean IGCC

Cryogenic ASU

Supplier : Air Products

ASU in a IGCC plant is used for....

- Oxidant O_2 of coal in a gasifier
- Diluent N_2 to reduce NOx in a gas turbine
- Process N_2 (high & low pressure) to be used in a gasification power block

Description	Purity(vol%)	Requirement (kg/h)	Temp(℃)	Pressure (bar)	Remarks
O_2	Approx. 95%	93,100	15	47.7	Oxidant
VHP N_2	≤ 0.1% O_2	54,720	80	83.7	Process N_2
LP N_2	≤ 0.1% O_2	15,950	40	7.5	Process N_2
Waste N_2	<1.9% O_2	220,726	120	30.5	Diluent N_2 for GT

20 TPD Gasification Test Facility at Taean IGCC

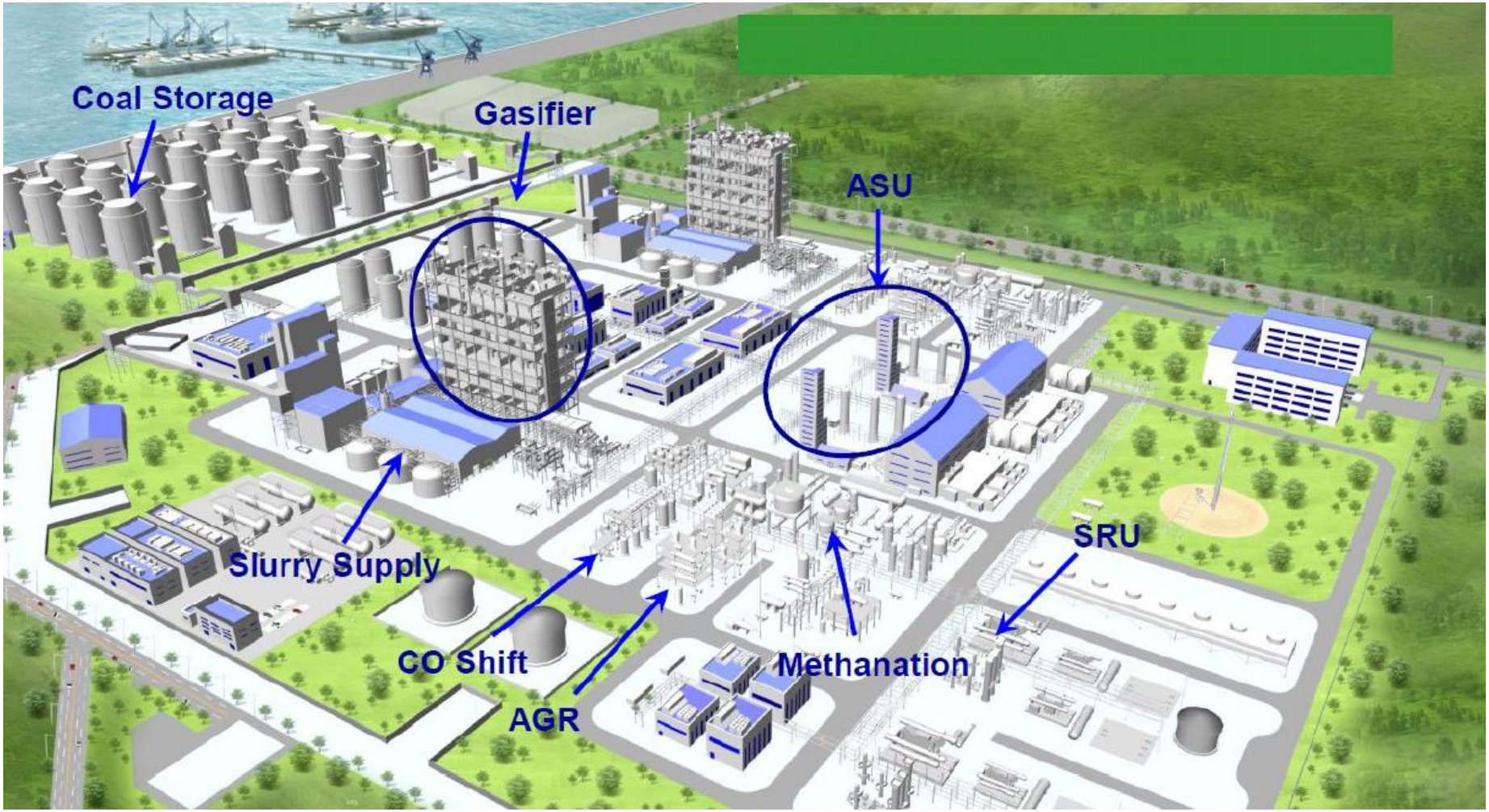
POSCO Gwangyang SNG Project

Project Outline

- **Location** **Gwangyang, Korea**
  - Site Size 100 Acre
- **Capacity** **500KTA of SNG**
  - **5,500 TPD Sub-bituminous Coal**
  - **ConocoPhillips** Gasifiers 2 + 1
  - **Linde** Rectisol for Acid Gas and CO_2 Separation
  - **HaldoTopsoe** Methanation Process
  - **Jacobs** FEED Contractor
  - **POSCO E&C** EPC Contractor
  - **Daewoo Eng.** Detail Eng. Contractor
- **Schedule** **'08.11 ~ '14.6**
  - '11.6.7 **Groundbreaking Ceremony**

Source: D. Ko, "Progress of Kwangyang Coal Gasification SNG Project," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

POSCO Gwangyang SNG Plant Layout

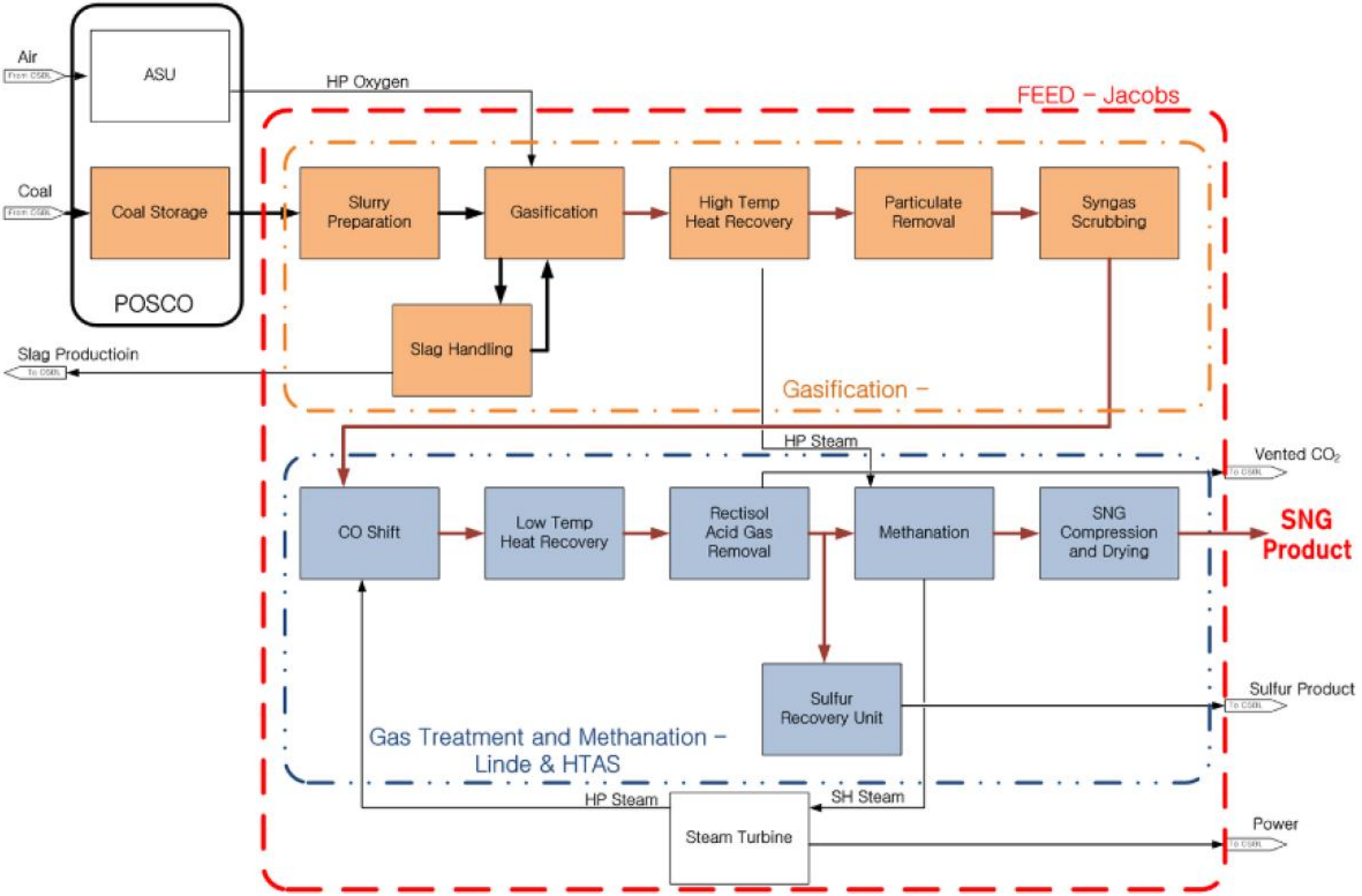


Source: D. Ko, "Progress of Kwangyang Coal Gasification SNG Project," Coal Gasification Symposium, KIChE Spring Symposium 2012, ICC Jeju, Korea.

POSCO Gwangyang SNG Plant Construction (2013/09)

Source: Updates on POSCO SNG Project, 2014 Gasification Technologies Conference, Colorado Springs, 2014/10.

Process Overview – POSCO SNG Project



Source: Updates on POSCO SNG Project, 2014 Gasification Technologies Conference, Colorado Springs, 2014/10.

Future Plan for Clean Coal Technology Power Plants in Korea

Construction Finish Year	Power Company	IGCC/CCT	Scale	Electricity Supply/Demand Master Plan
2015	Western Power Co.	**Taean IGCC**	**300 MW_e**	5th (2010/12), 6th (2013/12)
2017	Southern Power Co.	**Yeungnam IGCC**	**300 MW_e**	5th (2010/12), 6th (2013/12)
2019	Midland Power Co.	**Gunjang IGCC**	**300 MW_e**	5th (2010/12), 6th (2013/12)
2025	-	-	**300 MW_e**	6th (2013/12)
2026	-	-	**300 MW_e**	6th (2013/12)

- Actual Implementation might be delayed due to high construction cost and ambiguous CO_2 taxation policy
- When SNG projects are approved, IGCC → (Coal gasification + SNG) projects are more feasible.

Future Plan for SNG Projects by Korea Midland Power Co.

■ **Samchuk SNG Project** : 500,000 ton SNG/year, Site area 150,000 m^2
■ **Hadong SNG Project** : 500,000 ton SNG/year, Site area 150,000 m^2

- Use low grade coal (4,250 kcal/kg)
- Hopeful construction schedule : 2017/01 – 2019/12

Project approval dalay, Uncertainty in SNG selling price

Samchuk SNG Plant Site

Hadong SNG Plant Site

Limitations in More Wide Adaptation of IGCC

High Construction Cost

- High construction cost of over US$4,000/kW
- **In Korea's case,**
  Coal IGCC : US$3,800-4,300/$kW_e$
  USC : less than US$2,000/$kW_e$
  Conventional PC(Pulverized Coal) combustion-based power plant : US$1,300-1,400/$kW_e$

High COE (Cost of Electricity)

- Main Causes :
  - the First-of-a-Kind nature
  - oligopoly by few big companies (less competition)
  - small market size

Distorted Market by Government Incentives for Renewables

- (Europe) Electricity from wind, solar source are more favored by government policy. Coal-fired electricity generation costs more than renewables in some countries.

Slow Enhancement in Plant Availability

- Need technological jump in ASU, Gasifier feeding, Gasifier, Syngas cooler, filters, etc.

Textbook Cost for Earlier IGCC ('Gasification Technologies' 2005)

Project Cost

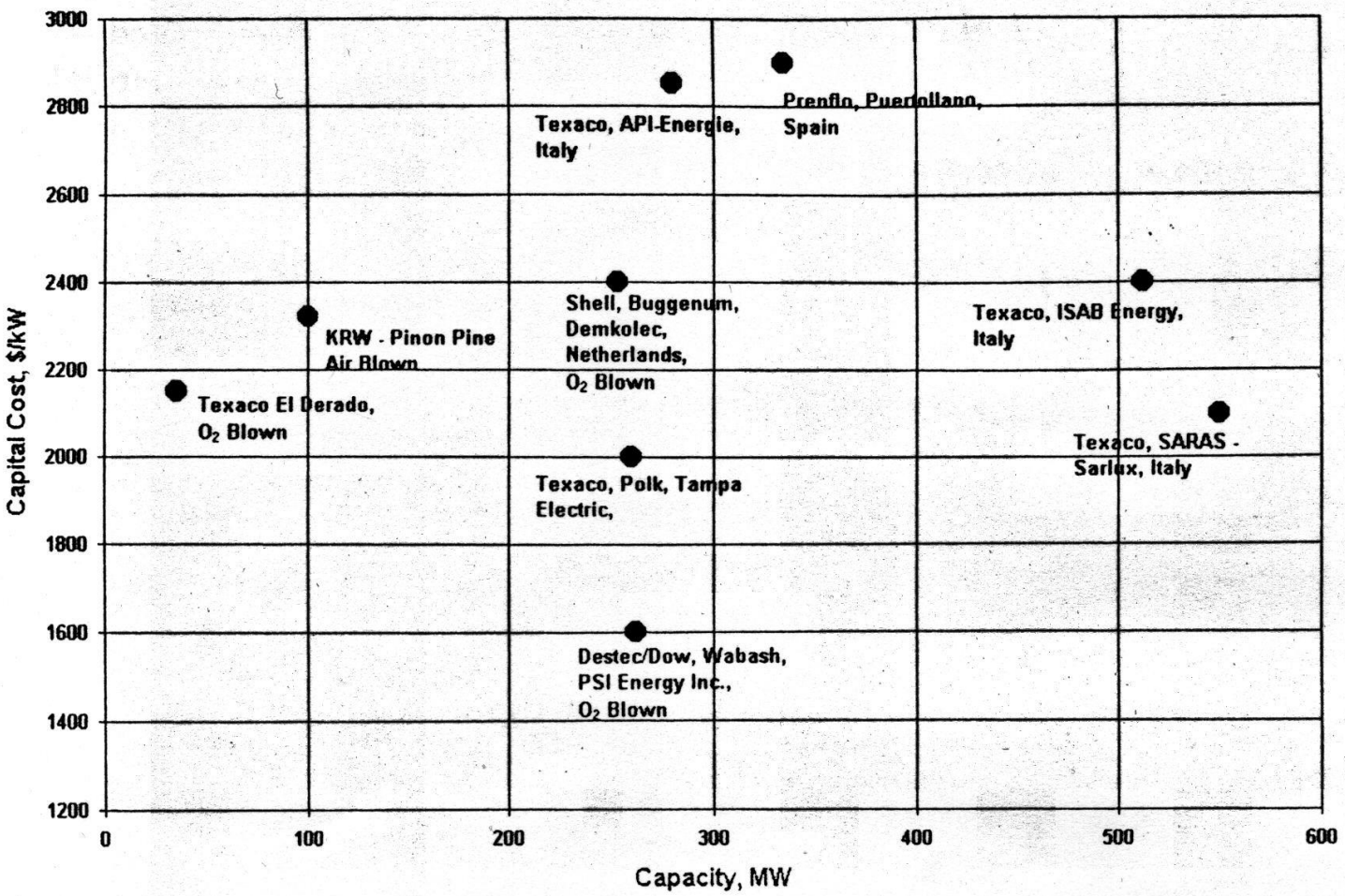
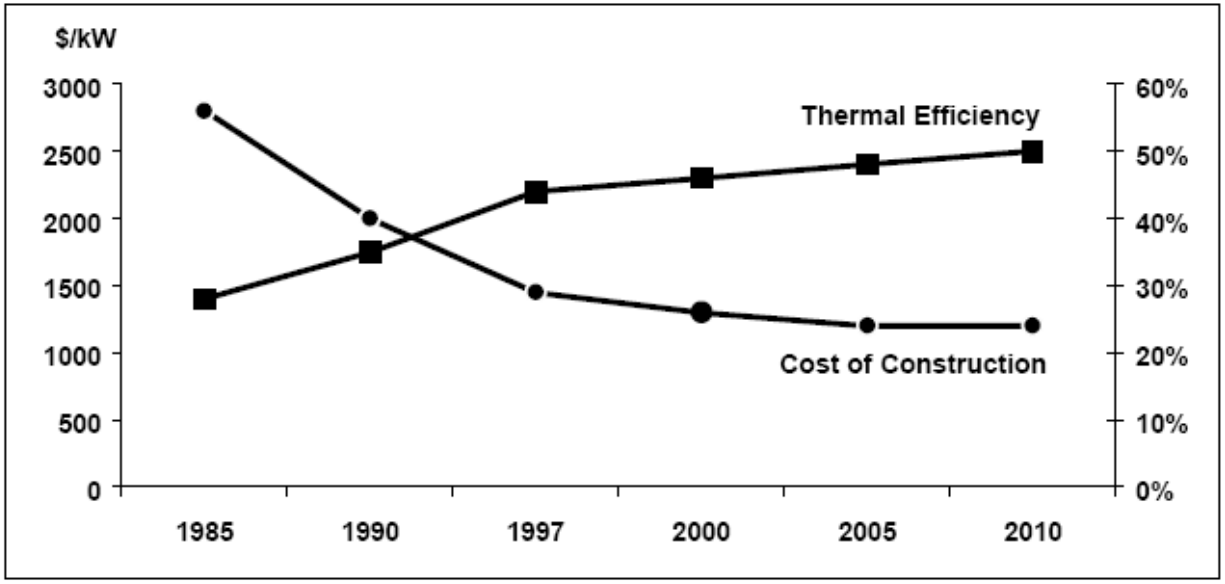


Figure 2.8 Capital costs reported for different demonstration/commercial projects.

Earlier Expected Data on IGCC Cost/Efficiency (1999/2)

Figure 2: Cost Pattern for IGCC



Source: Ferrier (1998)

Table 2 summarizes the estimates of capital and operating costs of coal-based power generation.

Table 2: Construction Cost of Coal-Based Power Generation

	PC	*PC +FGD*	*IGCC*	*PFBC*
Construction Cost ($/kW)	1,050	1,150	1,450	1,500
Thermal Efficiency (%)	34	34	42	40

Source: International Energy Agency (1996)

Source: 'IGCC in China', Nautilus Institute, 1999/02.

Cost Comparison with/without CO_2 Capture (EPRI, 2010)

Item / Case	Natural Gas Combined Cycle	Pulverized Coal Power Generation	IGCC
Construction Cost ($/kW) - No CO_2 capture	718	2,010	**2,505**
Construction Cost ($/kW) - with CO_2 capture	1,497	3,590	3,568
Cost of Electricity ($/MWh, 2007) - No CO_2 capture	59	59	**77**
Cost of Electricity ($/MWh, 2007) - with CO_2 capture	86	108	122

Source: EPRI, Cost and Performance Baseline for Fossil Energy Plants - Volume 1, Bituminous Coal and Natural Gas to Electricity, 2010/11

IGCC Cost (2012 Data)

IGCC Cases from U.S. EIA Generating Costs Update for 2012

Technology	Single Unit IGCC	Dual Unit IGCC	Single Unit IGCC w/ CCS
Power Block	2x1 F-Class	Two 2x1 F-Class	2x1 F-Class
Gasifier Block	E-Gas Slurry Feed 2 Trains	E-Gas Slurry Feed 4 Trains	
Feed	Ill. No. 6 Bit. Coal (11,666 Btu/lb HHV)		
Acid Gas Recovery Technology	COS cat, Selexol	COS cat, Selexol	WGS, 2-stage Selexol
Unit size, MWe Gross (Net)	(600)	(1200)	690 (520)
Auxiliary Load			
Thermal Efficiency (net – HHV)			
Heat Rate (Btu/MWh HHV)	8700	8700	10,700
Capacity Factor			
Cap Costs $/kW net	3,666 EPC 4,400 TPC	3,206 EPC 3,784 TPC	5,499 6,599 TPC
Cap Costs $/kW net (2009)[120]	3,706 TPC	3,348 TPC	5,559 TPC
Fixed O&M ($/kW-year)	62.25	51.39	72.83
Variable O&M ($/MWh net), 2012	7.22	7.22	8.45
Percentage of CO_2 emissions captured	90	90	90
SO_2 lb/MMBtu HHV	0.025	0.025	0.015
NO_x lb/MMBtu HHV	0.0075	0.0075	0.0075
CO_2 lb/MMBtu HHV	206	206	20.6

"TPC" = "overnight cost" including owners costs less financing. Costs are in Q4 2012 US dollars.

Ref. 120 : Updated Capital Cost Estimates for Electricity Generation Plants. U.S. Energy Information Administration. 2010/11.

US Edwardsport IGCC Case : 4,660 US$/kW (2014)

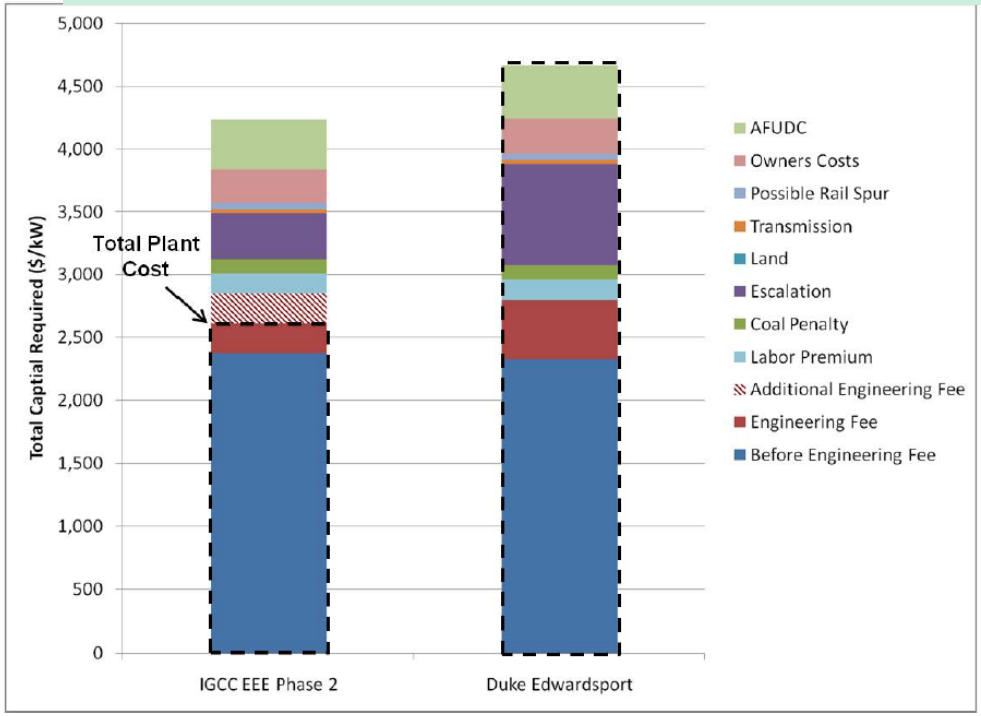


Figure 17-2
Comparison of Total Capital Required for Duke Edwardsport IGCC to EPRI EEE Case

- Net Output: 618 MW
- Heat Rate: <10,000 Btu/kWh
- Expected Availability
  - 75% for first 15 months
  - 85% for life of plant
- Power Block
  - 2 on 1 Configuration
  - Combustion Turbines: GE–7FB,syngas 236 MW (ea)
  - Steam Turbine: GE–G13,322 MW
  - HRSG's: Doosan Heavy Industries
- CCS-ready, but not installed

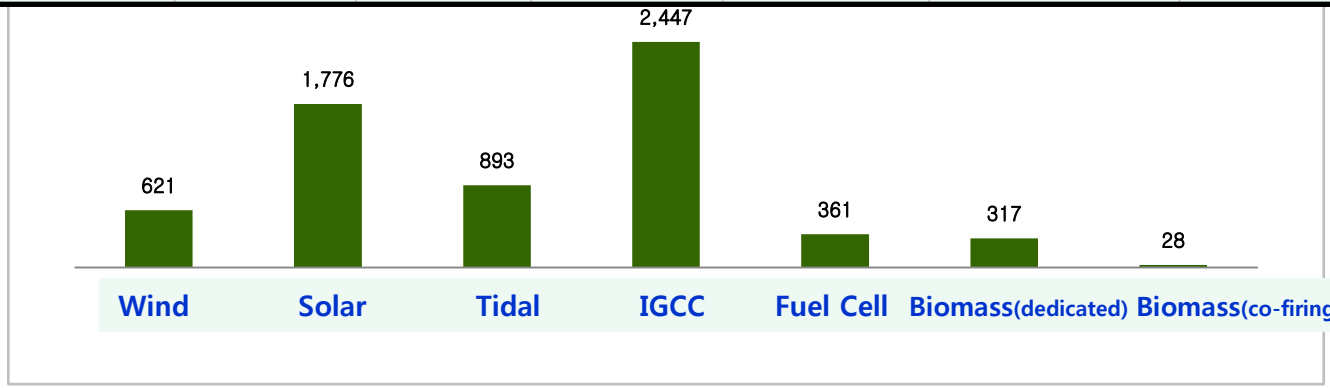
Source: Gasification Users Association: Technology Status – December 2013, EPRI Report 3002001511 .

Cost of Electricity for New/Renewable Energies in Korea

- Biomass co-firing using existing facility is the cheapest option.
- Currently, IGCC is the most expensive option due to its first-of-a-kind plant nature.

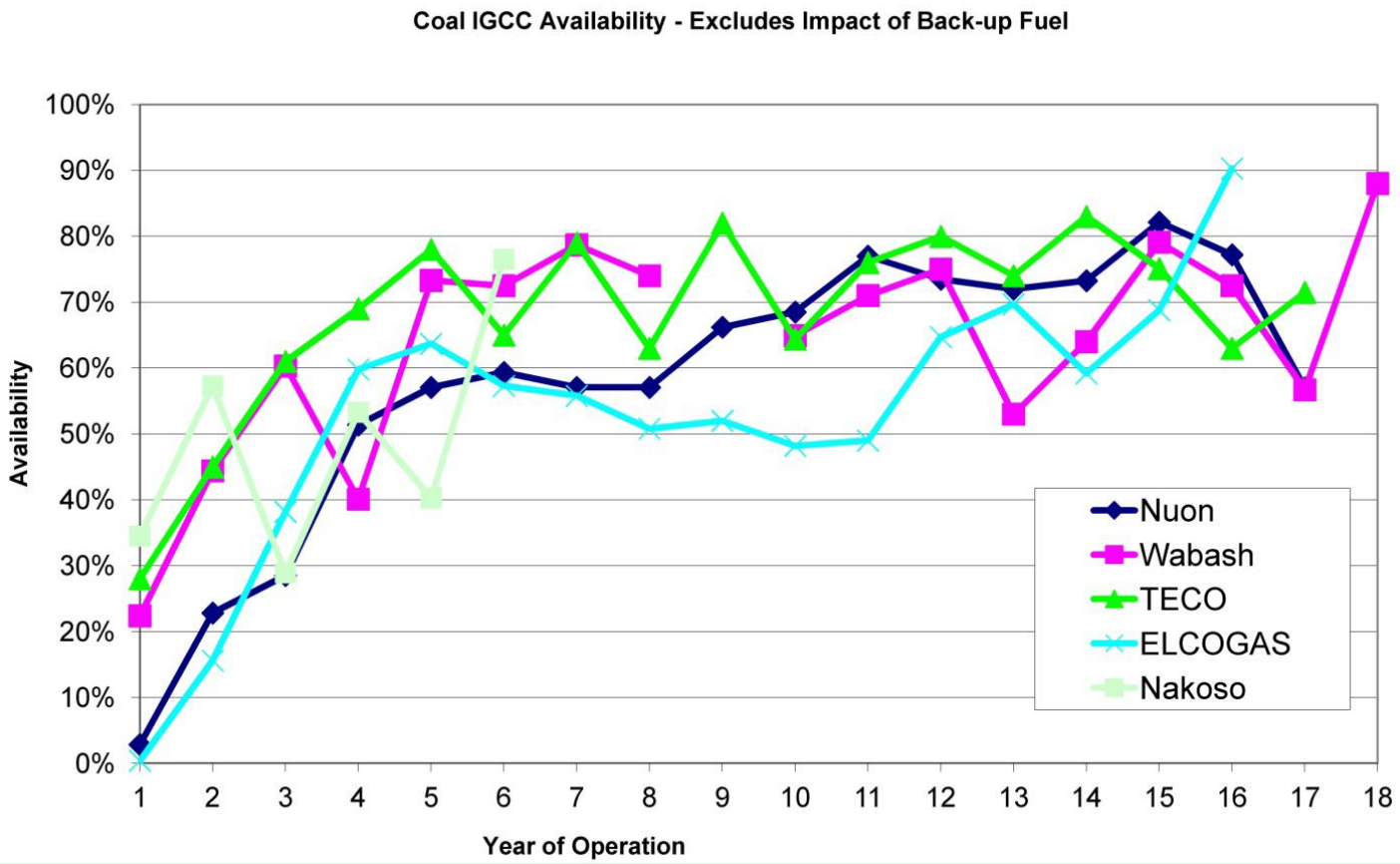
- Regulation for too high biomass dependence has started in Korea.
- IGCC takes time to reach mature technology status.
- Poly-generation options (SNG, FC) exist to overcome current limitations.

Item	Wind	Solar	Tidal	IGCC	Fuel Cell	Biomass	
						Dedicated-firing	Co-firing
Cost of Electricity (1,000 Won /MWh)	621	1,776	893	2,447	361	317	28



Source: Korea Western Power Co., "Bio-energy Power Generation Status of Korea's Power Companies", KAWET Fall Technical Workshop, 2013/10/30.

History of World Coal IGCC Plants Availability



- Recent plants can obtain 75-85% availability from trial-and-error's of Demo IGCC plants.
- Coal Gasification → SNG/Chemicals option is more easier by using proved technologies.
- Taean IGCC in Korea projects to reach 85-95% plant availability by 2020.

Figure Source: Gasification Users Association: Technology Status—December 2013, EPRI Report 3002001511 .

Recent Asian IGCC Projects and Future

■ **Recent Asian Coal IGCC Projects :**

- Two 500 MW Coal IGCC Projects in Fukushima (Japan, Tokyo Electric)
- Taean 300 MW Coal IGCC Project (Korea, Western Power Co.)
- GreenGen 300 MW Coal IGCC Project (China, Huaneng Group)

■ **Power Magazine (2014/07/01), Does IGCC Have a Future?**

What happens next may depend in large part on the success of the new Asian plants. "If those projects can avoid the large cost overruns that were encountered by the U.S. IGCC projects," "it will open the door to more IGCC projects not only in Asia but possibly elsewhere. If they cannot, it could doom the technology."

Application of Gasification Technology to Reliable/Economical Projects

■ **Recent Asian Refinery Residue IGCC Projects :**

- **Saudi Jazan IGCC project**: 2 billion US$, 16 gasifiers
- **India Jamnagar poly-generation project**: 4-5 billion US$, 8 gasifiers, Electricity/H_2/SNG/Chemicals co-production, Started construction 2013/04.

Power Magazine Source: http://www.powermag.com/does-igcc-have-a-future/?pagenum=1

Conclusions

- It appears imperative to utilize Clean Coal Technologies in Korea because Korea imports 97% of energy with the requirement of energy diversification and minimum 29-32% of electricity should come from imported coal.
- Commercial-scale IGCC and Coal-To-SNG plants are under construction in Korea, and 3-6 more projects are being reviewed.
- Right now is the struggle time for IGCC. With low-cost gasifier/syngas-cooler, air separation version in development, IGCC might take 5-10 years to get a competitive edge over other technologies.
- SNG/Chemicals production via coal gasification can be economical in far-east Asian countries, where NG/oil are expensive and in short supply.
- No clear decision was possible for the power company in constructing CCT plant when there was no legal obligation. But, from 2012, RPS system for new/renewable energies has been enforced in Korea.
- More stringent environmental and CO_2 regulation will increase the momentum for the CCT power plants in Korea.
- Realizing higher plant availability and lower cost are key factors, and need to improve manufacturing capability in nearby areas to lower the cost.


Discussion