Findings from Pre-workshop Study

Funded by APEC project "Promoting Energy Efficiency Enhancement in Electricity Generation"

Prof. Zhao Xu
The Hong Kong Polytechnic University

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Introduction

Project Goals

Aiming to promote accelerating the **phase-out of unabated fossil fuels** and **energy efficiency enhancement in electricity generation** to pursue strong, balanced, secure, sustainable and inclusive growth in the Asia-Pacific region.

Rising Energy Needs

Global energy demand is increasing rapidly. With economic growth and population rise, the need for electricity is projected to surge. This puts immense pressure on power generation sectors worldwide.

Carbon Reduction Challenge

The power sector is a major carbon emitter. To combat climate change, reducing carbon emissions from power generation, **nearly 40% in social carbon emissions**, is crucial. Countries are setting ambitious targets to lower carbon footprints.

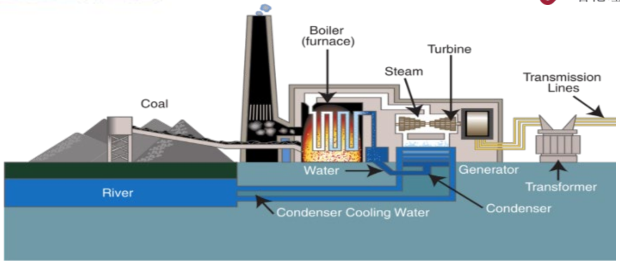
Sustainability Goals

Achieving sustainability in power generation is vital. This involves improving energy efficiency, optimizing energy structure, and reducing environmental impact to meet future energy needs responsibly.

Efficiency of Power Plants

1. Coal-Fired Power Plant

Net Electric Power Supply to Grid 35-42%



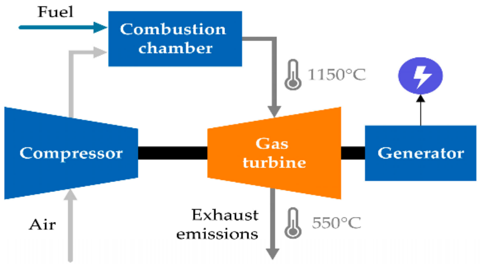
Converting coal into electricity

Chemical energy to thermal energy	Thermal energy to mechanical energy	Mechanical power to Electric Power	Energy consumption for plant operation
Loss: 6-10%	Loss: 40-45%	Loss: 1-3%	Loss: 2%
Boiler combustion converts coal's chemical energy into steam, incurring a 6–10% energy loss.	Thermal-to-mechanical energy conversion in the turbine results in a 40–45% loss of the input heat energy.	The generator converts mechanical to electrical energy with minimal losses of 1–3%.	A portion of the generated electricity is consumed by auxiliary equipment (e.g., pumps, fans, control systems).

Efficiency of Power Plants

2. Gas-Fired Power Plant

Net Electric Power Supply to Grid 40-60%



Converting gas into electricity

Chemical energy to thermal energy

Loss: 5-10%

Natural gas is burned in a gas turbine, producing high-temperature, high-pressure gas, about 5%-10% energy loss.

Thermal energy to mechanical energy

Loss: 30-45%

Gas turbines convert thermal energy into mechanical energy. The combined cycle system (CCGT) can improve energy efficiency, about 30%-45% loss.

Mechanical power to Electric Power

Loss: 1-3%

The generator converts mechanical energy from gas and steam turbines into electrical energy, with 1–3% energy loss.

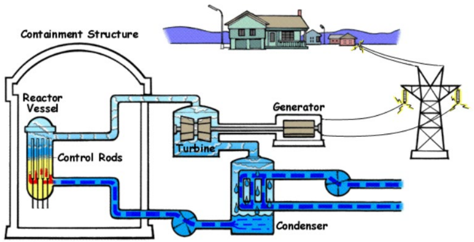
Energy consumption for plant operation

Loss: 4%

Some of the electrical energy is consumed internally by the plant, leading to an additional 4% energy loss.

Efficiency of Power Plants

3. Nuclear Power Plant



Converting nuclear into electricity

Net Electric Power Supply to Grid 30-34%

Energy loss during reactor heat output — **Loss: 2-5%**

In a nuclear reactor, the heat generated by the fission reaction of the nuclear fuel is absorbed by a coolant (usually water) and transferred to the steam generator, resulting in 2-5% energy loss

Thermal energy to mechanical energy — **Loss: 60-62%**

The lower operating temperatures and pressures in nuclear plants result in the **lower efficiency than coal-fired and gas-fired power** with about 38-40%of converting thermal energy to mechanical energy.

Mechanical to Electric conversion — **Loss: 1-3%**

The mechanical energy is converted into electrical energy by the generator, with about 1-3% loss.

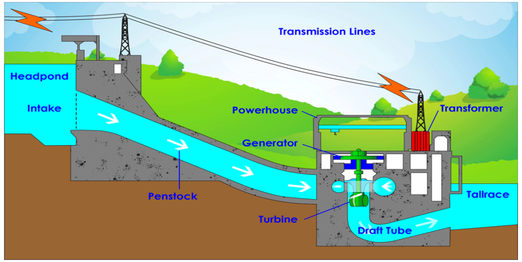
Energy consumption for plant operation — **Loss: 2%**

Electrical power generated is consumed within the plant for essential functions, about 2% loss.

Efficiency of Power Plants

Renewable energy is crucial for achieving carbon neutrality, providing low-carbon electricity to reduce greenhouse gas emissions. Assessing the efficiency of these technologies is key for guiding **sustainable energy transitions**.

4. Hydropower Power Plant



Converting water into electricity

Net Electric Power Supply to Grid 87-92%

kinetic energy to mechanical energy

Loss: 3-8%

Water drives turbine blades to convert kinetic energy to mechanical energy with 3–8% energy loss

Transmission loss to the generator

Loss: 2%

Mechanical energy from the turbine is transferred to the generator, with 2% energy loss.

Mechanical energy to electrical energy

Loss: 1%

The mechanical energy is converted into electrical energy by the generator, with 1%loss.

Energy consumption for plant operation

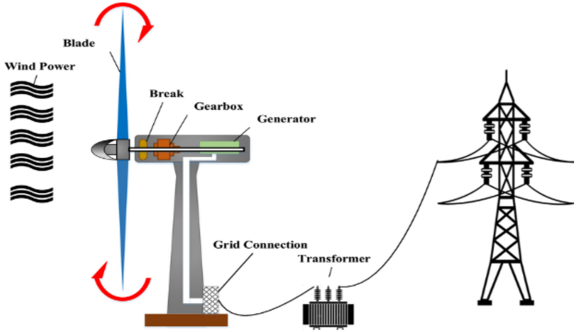
Loss: 2%

Part of the generated electricity is consumed by the plant's internal systems with 1%-3% loss.

Efficiency of Power Plants

5. Wind Power Plant

Net Electric Power Supply to Grid 32-42%



Converting wind into electricity

kinetic energy to mechanical energy

Loss: 50-60%

Due to air resistance and blade design inefficiencies, about 40-50% of wind energy is converted to mechanical energy.

Energy loss during energy passing to generator

Loss: 5%

Mechanical energy from the turbine is transmitted to the generator shaft, with 5% loss due to friction and gearbox conversion inefficiencies.

Mechanical energy to electrical energy

Loss: 1%

The generator converts mechanical energy into electrical energy with high efficiency, about 1% energy loss.

Energy consumption for plant operation

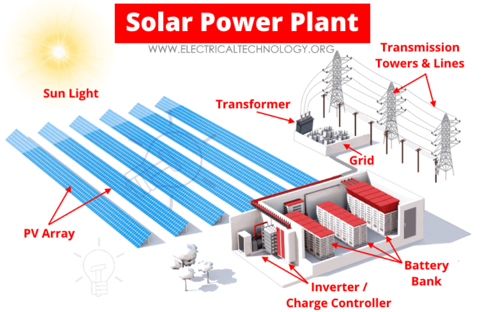
Loss: 2%

This typically results in an additional energy loss of around 2%.

Efficiency of Power Plants

6. Solar Power Plant

Net Electric Power Supply to Grid 12-19%



Converting solar into electricity

01 Solar radiation to electrical energy

Loss: 78-82%

Monocrystalline silicon photovoltaic panels convert sunlight into electrical energy through the photoelectric effect with 78%-82% loss.

02 DC to AC conversion

Loss: 2-5%

The direct current (DC) is converted into alternating current (AC) by the inverter with 2%-5% loss.

03 Energy consumption for plant operation

Loss: 1%

Some energy is consumed by internal systems such as monitoring, cooling, and control units, accounting for 1% of the total energy.

Efficiency of Power Plants

The energy efficiency of different electricity generation

Various types of power plants	Energy efficiency η	Various types of power plants	Energy efficiency η
Fuel-oil power plants	38% ~44%	Hydropower plant	
Coal-fired power plant		i) Large hydropower plant	about 95%
i) Sub-critical boiler	33%~37%	ii) Large hydropower plant	about 90%
ii) Supercritical boiler	37%~40%	Solar power plant	18% ~25%
iii) Ultra-supercritical boiler	40%~47%	Wind power plant	35% ~47%
Gas-fired power plant		Combined-cycle gas turbine	
i) Firing temperature 1000°C	30~35%	i) Firing temperature 1000°C	50~55%
ii) Firing temperature 1200°C	35~40%	ii) Firing temperature 1200°C	55~58%
iii) Firing temperature 1400°C	40~45%	iii) Firing temperature 1400°C	58~60%
iv) Firing temperature 1600°C	45~50%	iv) Firing temperature 1600°C	60~62%
Combined heat and power (CHP)	75%~90%	Nuclear power plant	33%~36%

Retrofitting of Existing Thermal Power Plants

Coal-Fired Power Plants

01 Boiler Upgrades

- Transition to **supercritical and ultra-supercritical boilers** increases efficiency up to **47%**.
- Reduces carbon emissions of power generated.

02 Combined Heat and Power (CHP)

- **Captures excess heat** from electricity generation for industrial or district heating.
- The energy efficiency of CHP systems can **reach 70%-90%.**

03 Installation of a Low-Temperature Economizer

- Recovers heat from flue gases to preheat the boiler's feedwater or air.
- This results in a **5%-10%** increase in thermal efficiency.

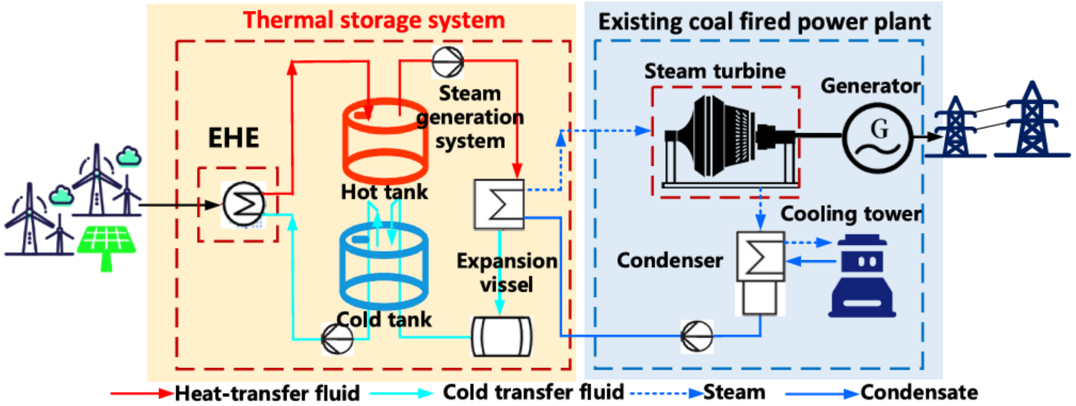
04 Condenser Optimisation

- Upgrading condensers, replacing old tube bundles with corrosion-resistant materials.
- These modifications lead to a **5%-10%** reduction in fuel consumption.

Retrofitting of Existing Thermal Power Plants

Coal-Fired Power Plants

Carnot Battery Reconstruction Model for Coal-Fired Power Plants



Carnot battery structure

- Retrofitting a coal-fired power plant with **electric heating, thermal energy storage, and a steam generator** transforms it into a Carnot battery, converting **renewable electricity into thermal energy** which is stored in the thermal energy storage. When electricity is required, this stored thermal energy can be converted back into electrical energy
- This transformation improves efficiency by **10-20%**, reduces fuel and lowers carbon emissions.

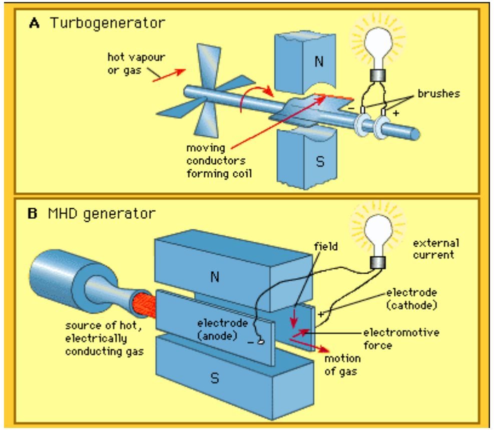
Source: Zhi Z, Ming Z, Bo Y, et al. Multipath retrofit planning approach for coal-fired power plants in low-carbon power system transitions: Shanxi Province case in China[J]. Energy, 2023, 275: 127502.

Retrofitting of Existing Thermal Power Plants

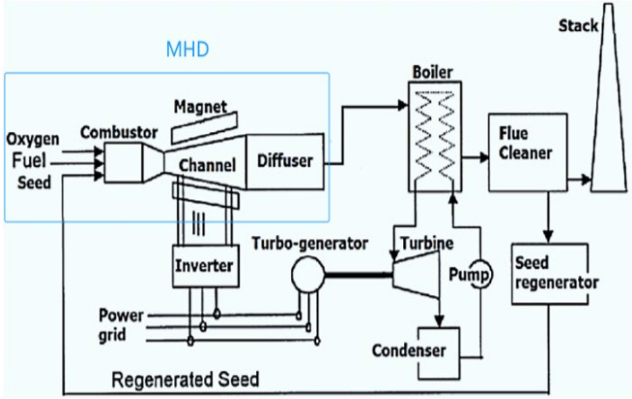
Coal-Fired Power Plants

06

Retrofit of Existing Thermal Power Plants with MHD Power Plant



Magneto hydrodynamic (MHD) power generation



Coal-fired MHD/steam retrofits plant using a gas connection

- Magnetohydrodynamic (MHD) power generation directly heats **coal** into a gas that is easily ionized, and uses the motion of **high-temperature conductive fluids** in a magnetic field to directly convert thermal energy into electricity.
- This combination of the thermal power plants with MHD power plant **improve energy efficiency up to 60%.**

Source: Poonthamil R, Prakash S, Varma A K. Enhancement of power generation in thermal power plant using MHD system[J]. IOSR J Mech Civil Eng, 2016, 13: 142-146.

Retrofitting of Existing Thermal Power Plants

Summary of retrofitting coal-fired power plants

- **Improving boiler efficiency** has low investment costs and **high cost-effectiveness**.
- **Combined heat and power generation** is particularly cost-effective in areas with **high thermal energy demand**.
- The installation of **low-temperature economizers** is highly cost-effective for **smaller coal-fired plants**.
- Condenser optimization and carnot battery reconstruction offer significant efficiency improvements with relatively high investment costs.
- Coal-fired MHD systems have **low technical maturity**, result in low cost-effectiveness.

Improving boiler, **combined heat and power generation** and **the installation of low-temperature economizers** is particularly cost-effective retrofit method for coal-fired power plant.

Retrofitting of Existing Thermal Power Plants

Gas-fired power plant

01 Combined Cycle Power Generation Technology

- Integrating gas turbines and steam turbines capture exhaust heat to **produce additional electricity**.
- The energy efficiency can reach **50%-60%.**

02 Upgrading Gas Turbines

- Using high-temperature materials and optimizing blade designs to enhance efficiency.
- This increases power generation by **10-12%**.

03 Improve Combustion Efficiency

- Combustion technologies: premixed combustion, wet compression technology, and staged combustion, optimizing burner design
- A **5%-10%** increase in thermal efficiency.

04 Optimizing Cooling System

- Optimizing condenser through improved design, materials and operational management.
- **5%-7%** increase in power generation efficiency.

Retrofitting of Existing Thermal Power Plants

Summary of retrofitting gas-fired power plants

- Combined cycle technology can provide a **significant energy efficiency** improvement and a relatively high cost-effectiveness **despite higher initial costs**.
- Upgrading gas turbines featuring medium investment can **significantly improve energy efficiency,** which is a **high cost-effectiveness** retrofiting option.
- Improving combustion efficiency and optimizing the cooling system offer relatively high cost-effectiveness with low investment but **limited energy efficiency improvement**.

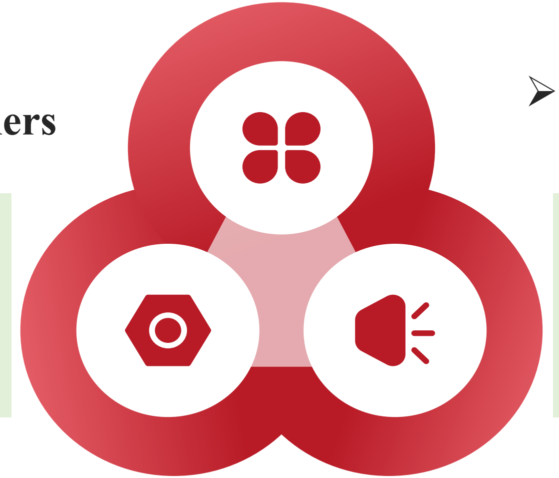
Combined cycle technology and **upgrading gas turbines** is particularly cost-effective retrofit method for gas-fired power plant.

Emerging Energy-efficient Generation Technologies

Coal-Fired Power Plants

Integrated Gasification Combined Cycle (IGCC)

IGCC converts coal into syngas for cleaner and more efficient power generation.



Ultra-supercritical (USC) Boilers

USC boilers operate at high temperatures and pressures, increasing thermal energy transfer efficiency.

Circulating Fluidized Bed (CFB) Combustion

CFB combustion ensures complete and cleaner combustion, reduces NOx and SO_2 emissions, and enhances efficiency.

Emerging Energy-efficient Generation Technologies

Gas-Fired Power Plants

01

02

03

High-Efficiency Gas Turbines

High-efficiency gas turbines, such as H-Class and J-Class, achieve efficiencies greater than 60%.

Kalina Cycle Technology

An ammonia-water mixture enhances heat absorption, extracting more energy from low-temperature sources to improve power generation.

Hydrogen Co-Firing

Blending hydrogen with gas improve energy efficiency due to hydrogen's **higher flame speed, higher temperature** and **wider flammability range**, enabling more complete and stable combustion.

Emerging Energy-efficient Generation Technologies

Nuclear Power Plants

Advanced Reactor Designs

Generation IV reactors, including fast neutron reactors and molten salt reactors, improve fuel efficiency and reduce nuclear waste.

Small Modular Reactors (SMRs)

SMRs offer modular design, passive safety, flexible fuel use, and load-following capability, enhancing sustainability and reliability.

Spent Fuel Recycling

Recycling spent fuel extracts valuable materials, reducing the need for mining and minimizing nuclear waste.

Emerging Energy-efficient Generation Technologies

Hydropower Power Plants

01

Variable-Speed Pumped Storage

Variable-speed pumped storage adjusts turbine speed to maintain high efficiency under varying water flow conditions.

02

Hydrokinetic Turbines

Hydrokinetic turbines convert water flow into electricity without dams, offering a sustainable and eco- friendly alternative.

03

System Optimization

Optimizing hydropower systems through advanced controls and design improvements enhances efficiency.

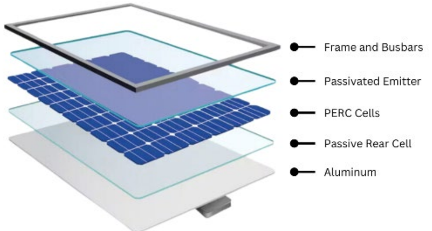
Emerging Energy-efficient Generation Technologies

Solar Power Plants

Advanced Photovoltaic Materials

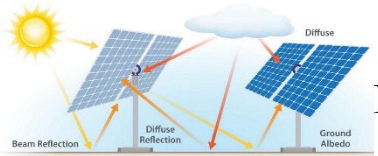
Perovskite Solar Cells, thin- film solar cells, N-type Silicon Solar Cells and so on offer higher efficiency and lower production costs.

PERC Solar Panel



PERC (Passivated Emitter and Rear Cell) Solar Cells

Passivation layer boosts light absorption, and rear cell optimizes the back passivation and reflection design, enhancing secondary absorption of photons, achieving more than 22% efficiency.



Bifacial Solar Panels

Bifacial solar panel is any photovoltaic solar cell that can produce electrical energy when illuminated on either of its surfaces, front or rear, increasing power generation by 10%- 30% on reflective surfaces.

Emerging Energy-efficient Generation Technologies

Wind Power Plants

Advanced Turbine Designs

Larger, more efficient wind turbines with taller towers and longer blades capture more wind energy, enhancing efficiency.

Variable Pitch Control

Real-time adjustment of blade angles optimizes energy capture across wind speeds, reducing mechanical stress and extending turbine lifespan.

Wake Steering

Adjusting turbine orientation to redirect wake enhances wind farm performance without extra infrastructure.

Recommendations

Electricity Generation

- Shift from coal to low-carbon generation (natural gas & renewables).
- Invest in efficient power generation & energy storage for grid stability.
- Promote a diversified mix of nuclear, renewables, and efficient fossil fuels.

Retrofitting Existing Thermal Power Plants

- Coal-Fired Power Plants: Upgrade boliers, install low-temperature economizers, and implement combined heat and power (CHP) systems.
- Gas-Fired Power Plants: Adopt combined cycle power generation and upgrade gas turbines for higher efficiency.

Innovation in Energy Technologies

- Enhance the integration and utilization of renewable energy.
- Ensure affordable, resilient, and accessible energy solutions.
- Support economic growth and energy security.
- Accelerate the energy transition and reduce carbon emissions.

Thank You