Allocating CO_2 Emissions from Cogeneration Systems

Descriptions of Selected Output-Based Methods

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Overview

- Introduction
- Background: cogeneration and exergy
- CO_2 allocation measures
- Examples
- Generalizations
- Closing remarks

Introduction

How would you allocate emissions from a process to the products if there was only one product?

If there were two products?

Introduction

Key Issue - Allocating CO_2 emissions can be confusing:

Easy:

- Single product (e.g., electricity)
- Multiple same products

Hard:

- Multiple different products

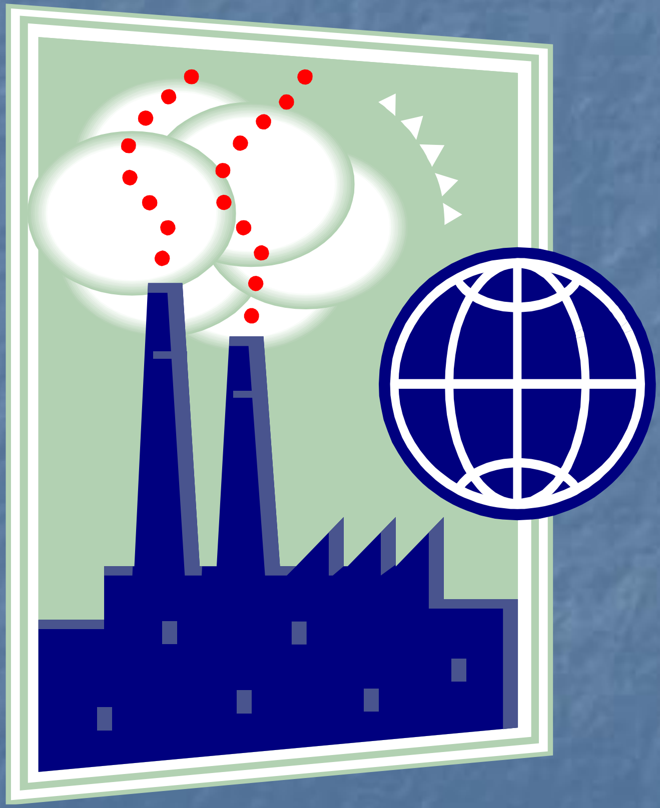
Scope

- Cogeneration
- Carbon dioxide emissions

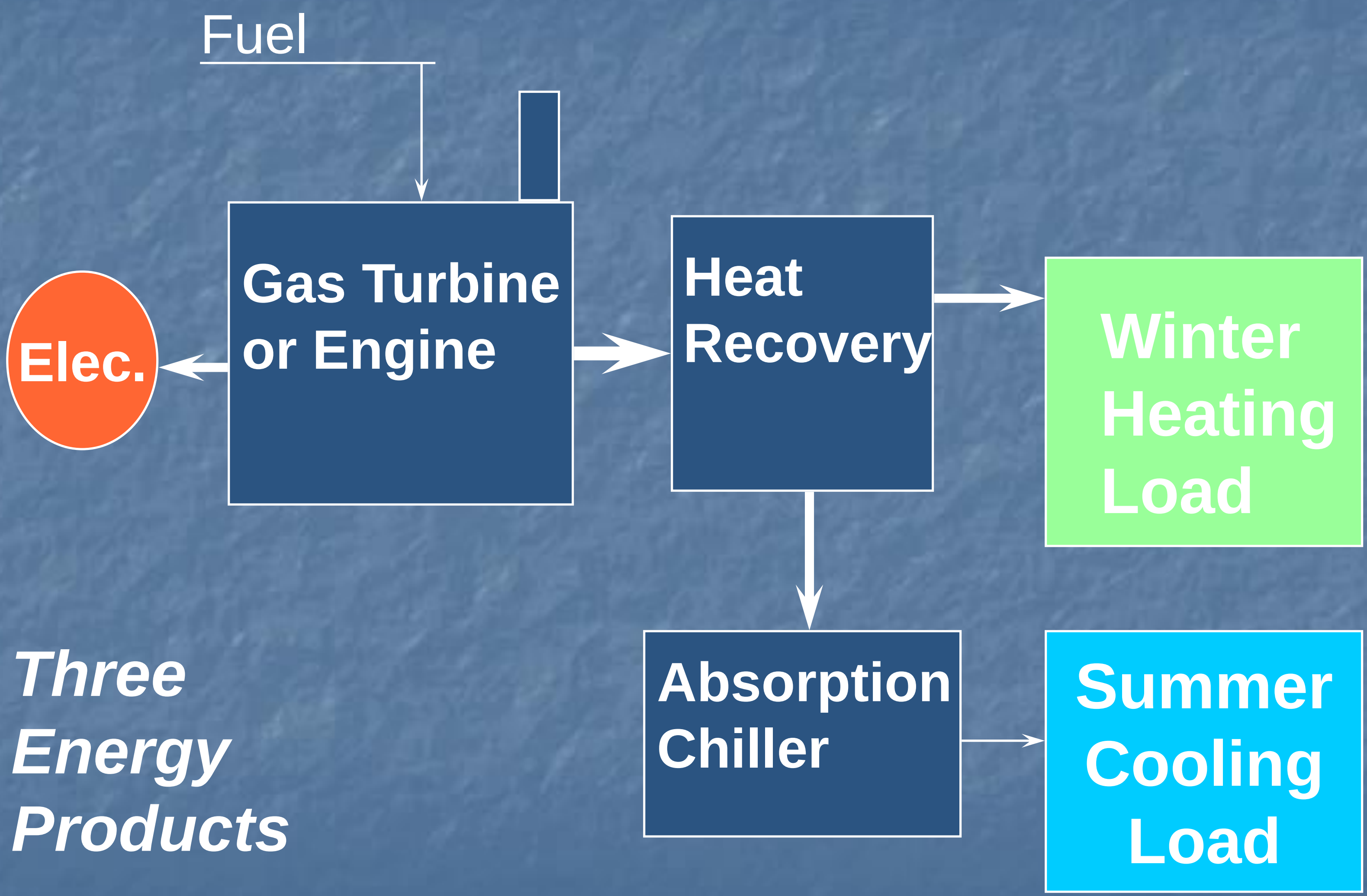
Cogeneration

Cogeneration

- Simultaneous production of thermal and electrical energy in a single plant

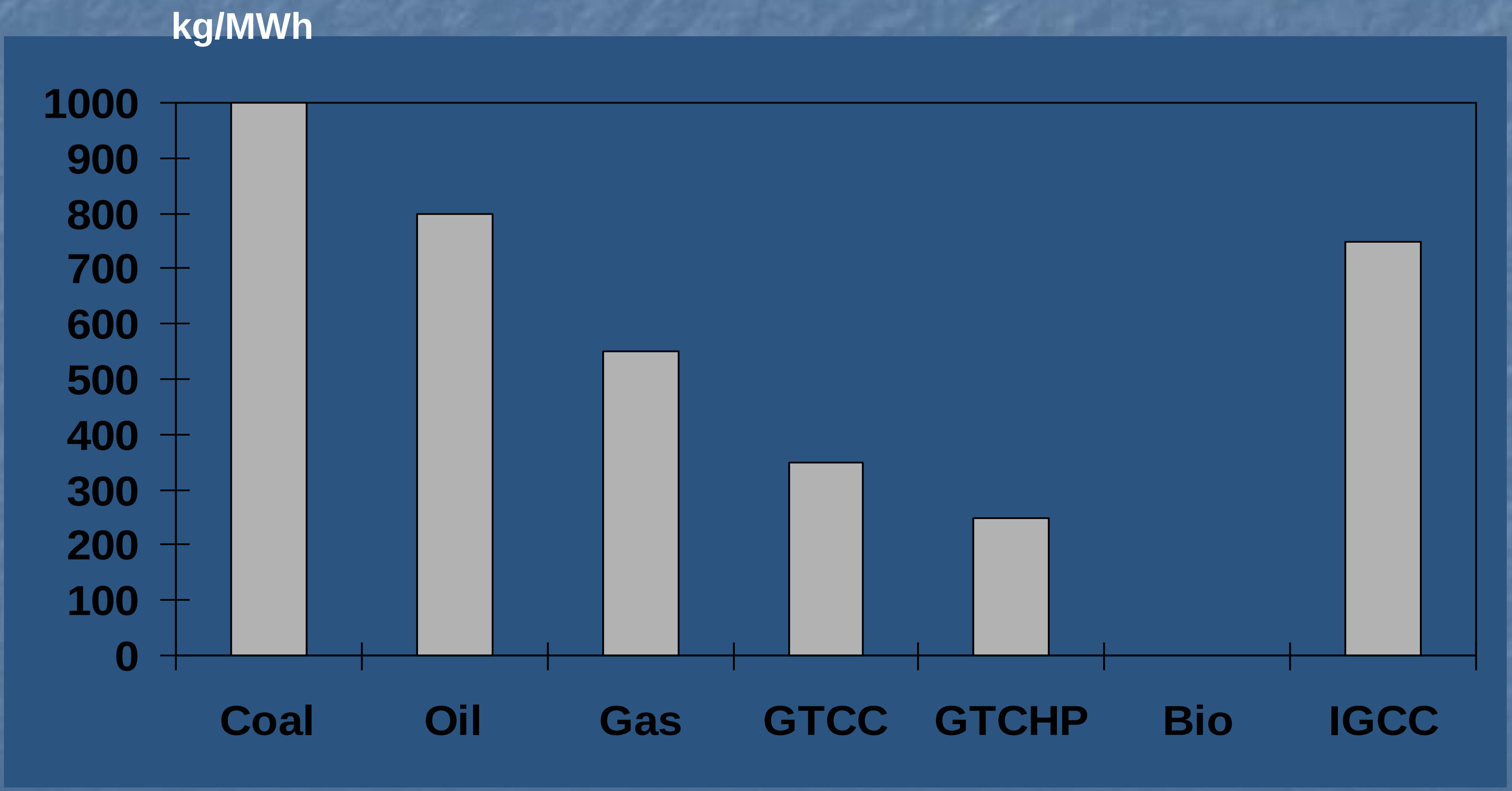


Cogeneration (and Trigeneration)



Three Energy Products

Comparison of CO_2 Emissions from Various Power Generation Plants



Why do bio processes (i.e., processes that use biomass or other bioresources) have zero carbon dioxide emissions?

Exergy

What is Exergy?

- Measure of usefulness of a given quantity or flow (maximum work potential in a specified environment)
- Some energy forms are more valuable (i.e., more work potential) than others (e.g. kinetic vs. thermal energy) and hence have more exergy

Exergy Analysis

- Evaluates for processes and devices thermodynamic behaviour (e.g., efficiencies, internal/external losses)

- Exergy analysis:
  - differs from energy analysis
  - is based on 2nd Law of Thermodynamics
  - relates consumption of exergy (or work potential) to entropy creation

Benefits of Exergy Analysis

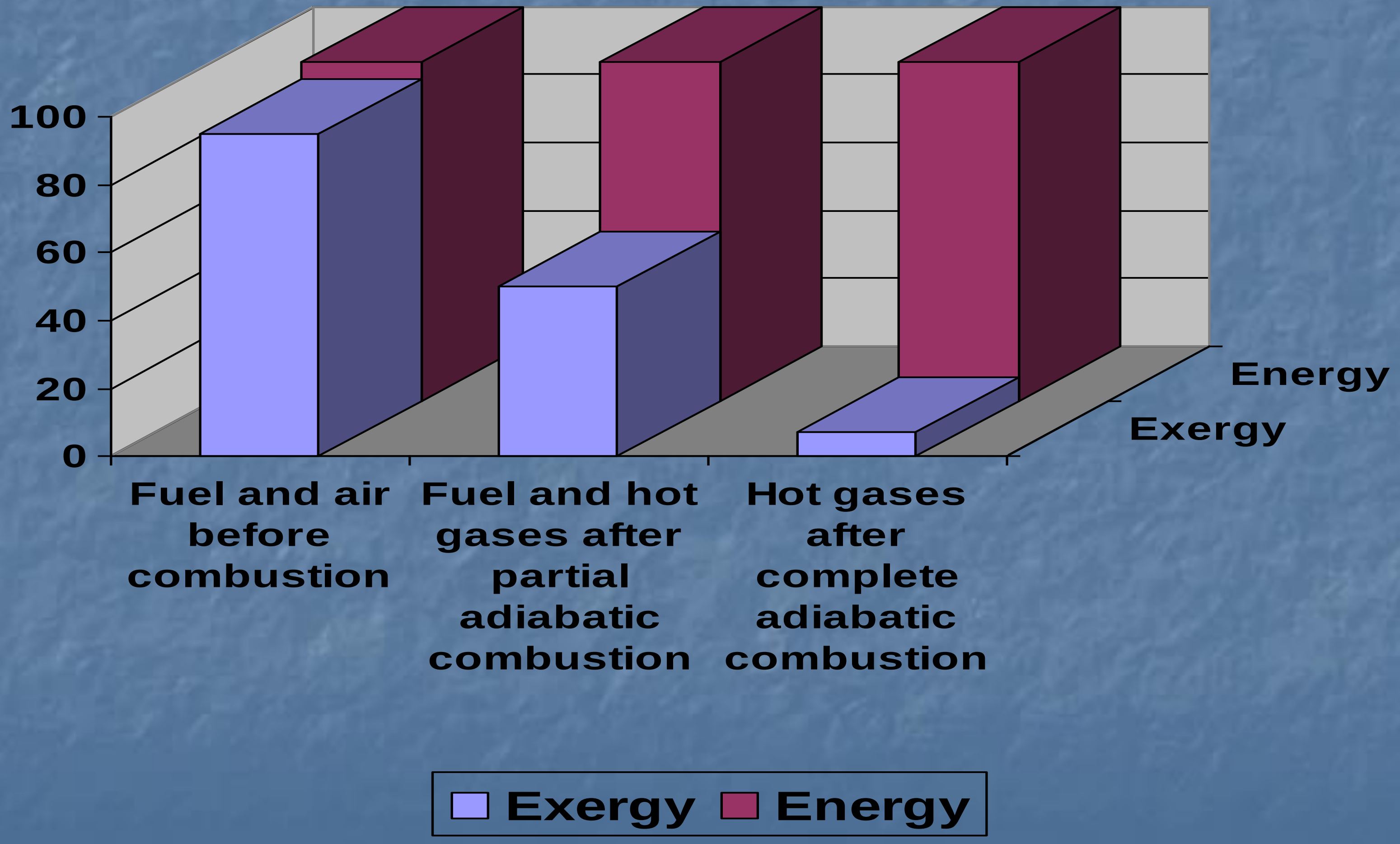
- Exergy analysis is advantageous to energy analysis
  - Energy efficiencies for an ideal system (eg, Carnot cycle) are not necessarily 100% but exergy efficiencies are
  - Losses are better characterized (cause, location, type)

Quality of Energy

- Electricity & Shaft Power — High
- Industrial Process Heat
- Cooling (*depends on temp.*)
- High Pressure Steam
- Hot Water
- Space Heating — Low

Why does high-temperature industrial heat have more exergy (or a higher quality) than space heat?

Fig. 1. Qualitative comparison of energy and exergy during combustion



CO_2 Allocation Methods for Cogeneration

CO_2 Allocation Methods for Cogeneration

- Energy Content of Products
- Exergy Content of Products
- Economic Value of Products
- Incremental Fuel Consumption to Electrical Production
- Incremental Fuel Consumption to Thermal Energy Production
- Shared Emission Savings Between Electrical and Thermal Energy
- Agreement
- Other Factors

CO_2 Allocation Method for Cogeneration Based on Energy Content of Products

- Allocations evaluated in proportion to energy contents of products
- Straightforward and simple
- Ignores quality of energy (so often underestimates share of emissions allocated to electrical product)

CO_2 Allocation Method for Cogeneration Based on *Exergy* Content of Products

- Allocations evaluated in proportion to exergy contents of products
- Accounts for quality and quantity of energy
- Avoids underestimating share of emissions allocated to electrical product

CO_2 Allocation Method for Cogeneration Based on Economic Values of Products

- Allocations evaluated in proportion to economic values of products
- Problem: economic values can be determined via several measures (eg, costs to produce commodities, prices)
- Not technically rigorous

CO_2 Allocation Method for Cogeneration Based on Incremental Fuel Consumption to Electrical Production

- Emissions allocated by dividing total fuel consumed among products, while considering electricity generation a by-product of thermal energy production
  1. Fuel consumption attributed to thermal energy production evaluated as hypothetical fuel consumed by an independent device
  2. Fuel consumption attributed to electricity generation evaluated by subtracting this hypothetical fuel from total fuel used

CO_2 Allocation Method for Cogeneration Based on Incremental Fuel Consumption to Thermal Energy Production

- Emissions allocated by dividing total fuel consumed among products, while considering thermal energy production a by-product of electricity generation
  1. Fuel consumption attributed to electricity generation evaluated as hypothetical fuel consumed by an independent device
  2. Fuel consumption attributed to thermal energy production evaluated by subtracting this hypothetical fuel from total fuel used

CO_2 Allocation Method for Cogeneration Based on Shared Emission Savings Between Electrical and Thermal Energy

- Allocations evaluated for each product in proportion to hypothetical fuel that would be used to produce that product independently, relative to the total hypothetical fuel that would be used to produce both products independently

Is there any rigorous theoretical reasoning for any of the methods for allocating carbon dioxide emissions in cogeneration?

Examples

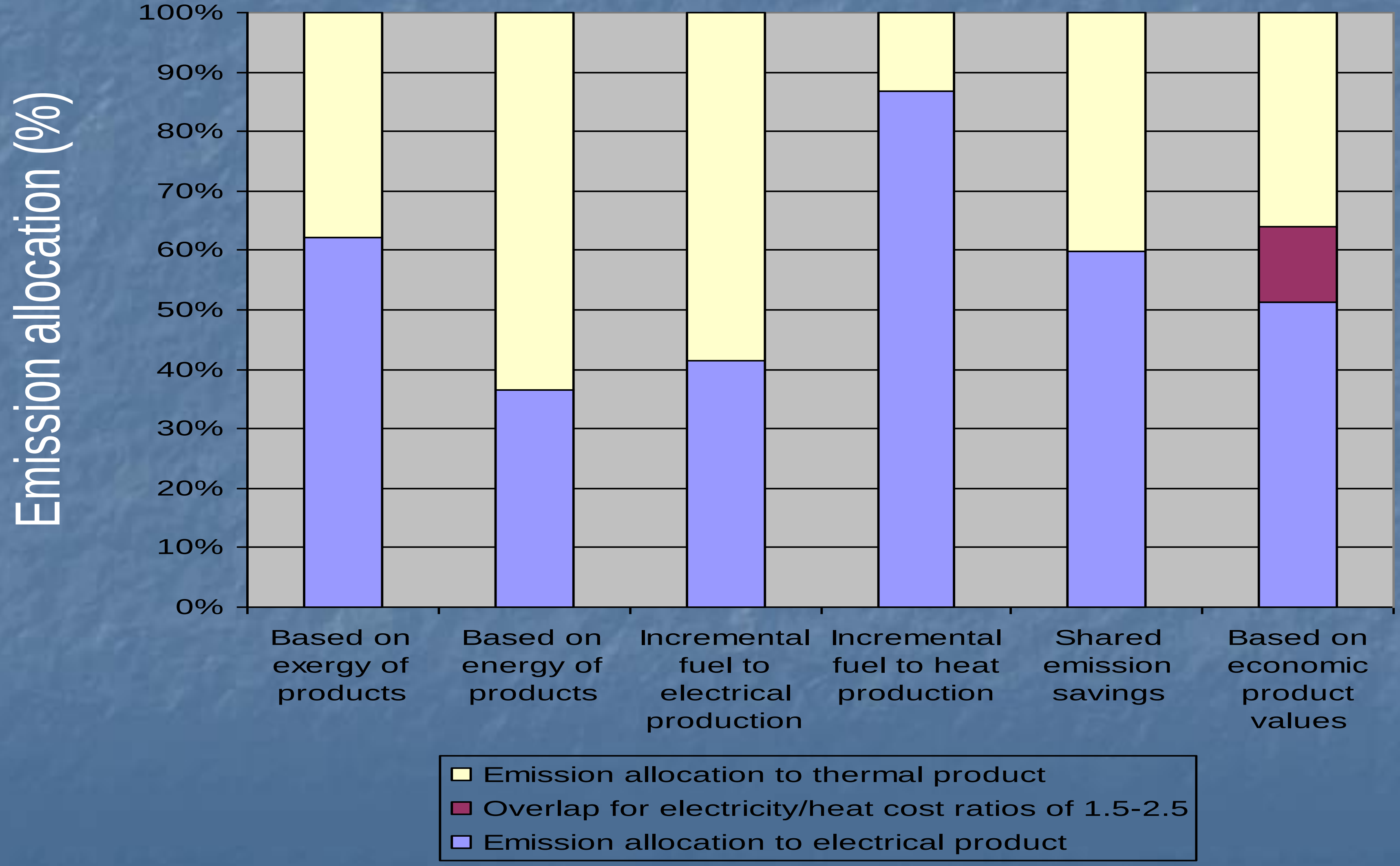
Examples

- University of Toronto Cogeneration System
- Cornwall Cogeneration and District Energy System

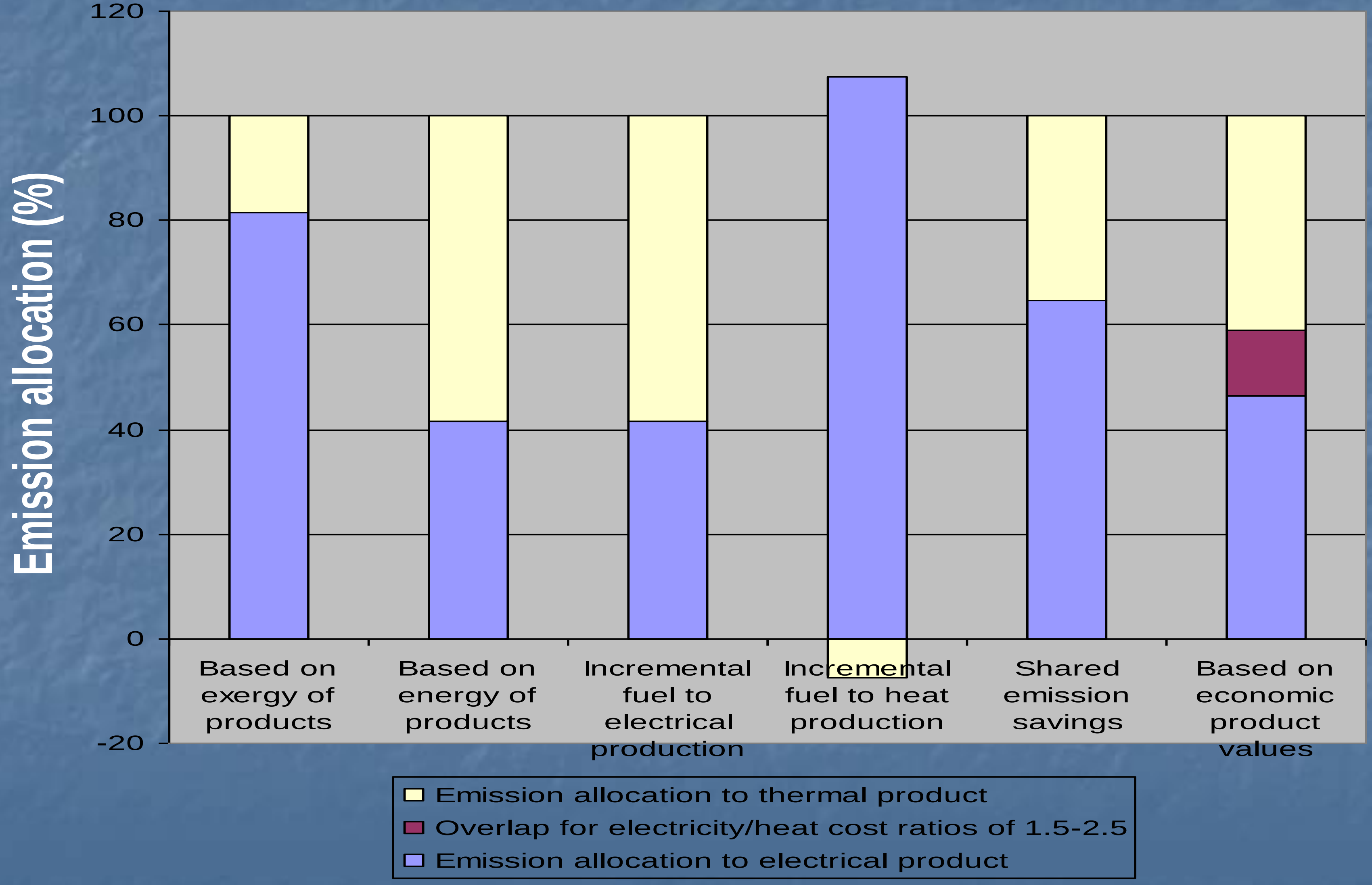
Table 4. Technical Parameters for the Cogeneration Systems Considered

Parameter	University of Toronto Cogeneration System	Cornwall Cogeneration and District Energy System
Engine type	Gas turbine	Two reciprocating engines
Heat use	Heating of campus using 6 km steam tunnel system	Municipal district heating using 4.5 km hot-water distribution network
Heat quantity and type (base load)	30,000 lb/hr of 200 psi steam	7 MW via 120°C and 1585 kPa steam
Supplemental firing	Heat recovery steam generator can be supplementary-fired to 90,000 lb/hr steam at 200 psi	None
Environmental controls	Water injection to control NOx emissions (to 42 ppm)	Engines use lean-burn technology
Installation date	1993	1995

Allocation of emissions for University of Toronto cogeneration plant (based on data in Table 6)



Allocation of emissions for Cornwall cogeneration and district heating system



Would the methods for allocating carbon dioxide emissions in cogeneration be important for cap and trade systems for carbon?

Generalizations

Generalizations - 1

- Multiple products (beyond cogeneration)
- Trigeneration
- Different commodities than electricity and heat (eg, hydrogen and oxygen)

Generalizations - 2

- Allocate costs among products more rationally, yielding better pricing, for cogeneration and related processes

How would you use this methodology to allocate costs to the products of cogeneration?

Would it be important?

Closing Remarks

Conclusions

- Many methods for allocating carbon dioxide emissions for cogeneration systems
- Methods differ significantly and results vary
- Exergy-based method felt to be most meaningful and accurate
- Important to allocate CO_2 emissions appropriately so environmental benefits of cogeneration better understood and exploited
- Results may provide basis for a meaningful overall approach for emissions trading