A criterion for selecting renewable energy processes

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What is the objective

- Renewable energy is the means, not the end. The atmosphere is the end.
- Society's willingness to pay appears to be limited.
- Buying the most $CO_{2\ eq}$ from the atmosphere per dollar is the objective.

Wise choices are the difference between tokenism and real impact

- Canada's per capita emissions: 20 tonnes

- 1% of GDP could reduce emissions by
  - 100% at $20 per tonne.
  - 7% at $300 per tonne.

- Some payments in Canada exceed $300 per tonne of $CO_{2\,eq}$.

Hence

- Variable carbon credits for the same unit of end use energy dissipate social funds.
- The overall lowest incremental cost per tonne of $CO_{2\ eq}$ avoided is the optimal selection criterion.

Illustrating the approach

- Straw / corn stover:
  - Abundant, annual, contiguous in many areas
  - Collection infrastructure in place
  - Studies indicate low relative cost
- But what to make:
  - Power from gasification or direct combustion
  - Ethanol via enzymatic fermentation
  - Diesel via Fischer Tropsch

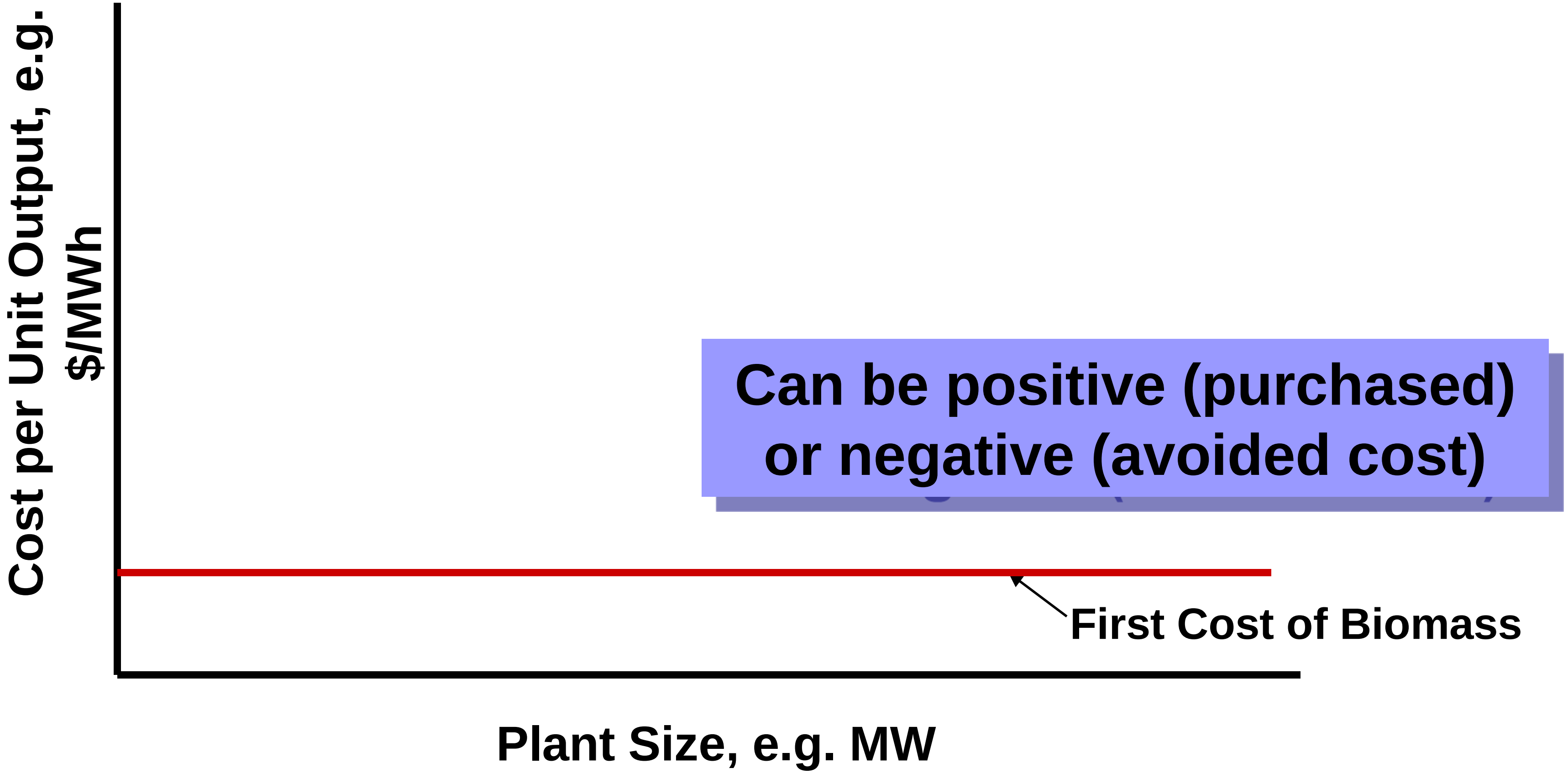
For each process

- What is the appropriate size of plant, and what is the product cost at that size?
- How much CO_2 equivalent is avoided?
- How much extra does someone (the taxpayer or the consumer) pay compared to a business as usual case.

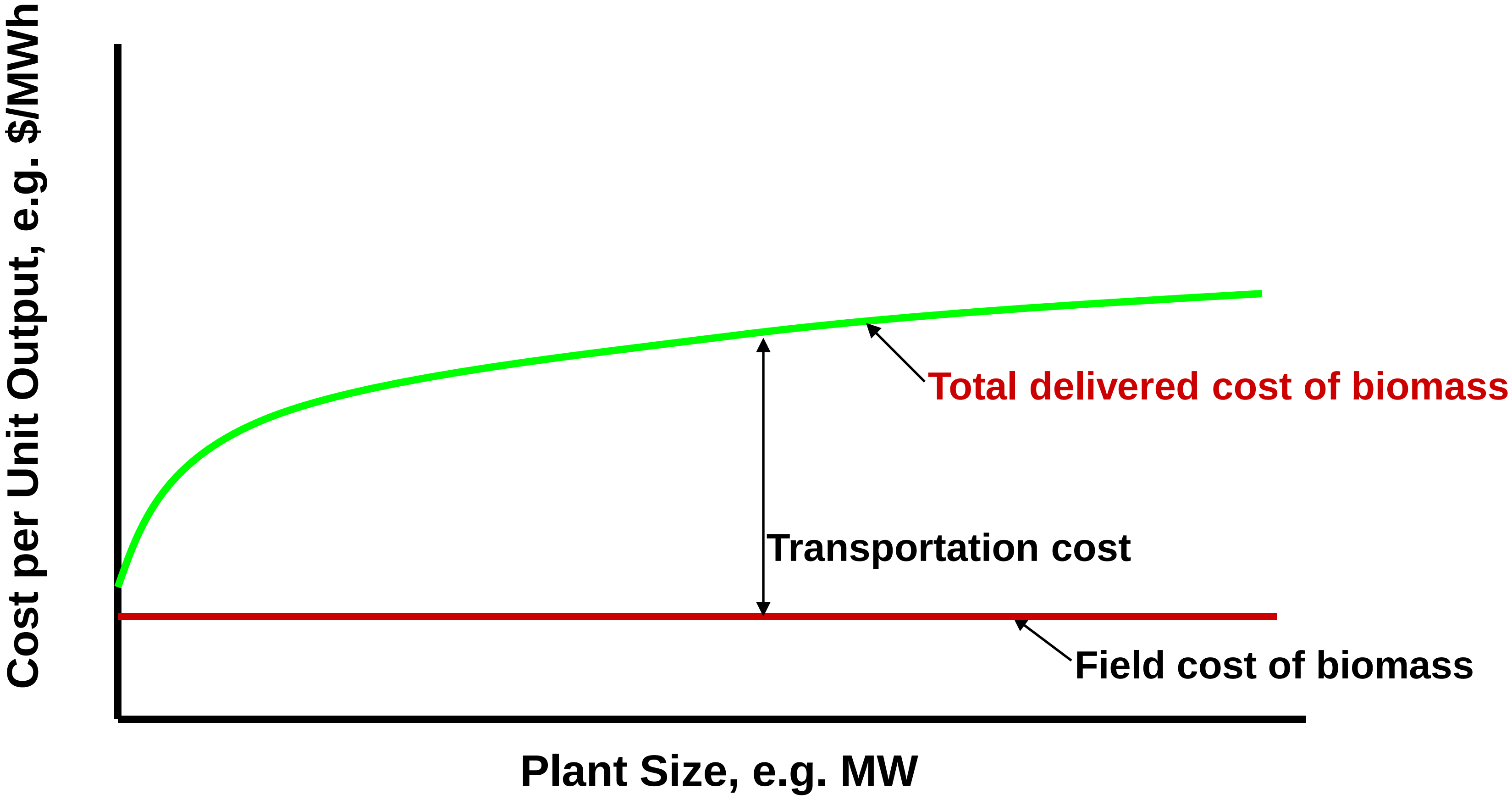
Bioenergy plants have an optimum size

- Three cost components: get it, move it, process it.
- The cost of transport and processing compete, creating an optimum size.
- Small plants are profoundly uneconomic.

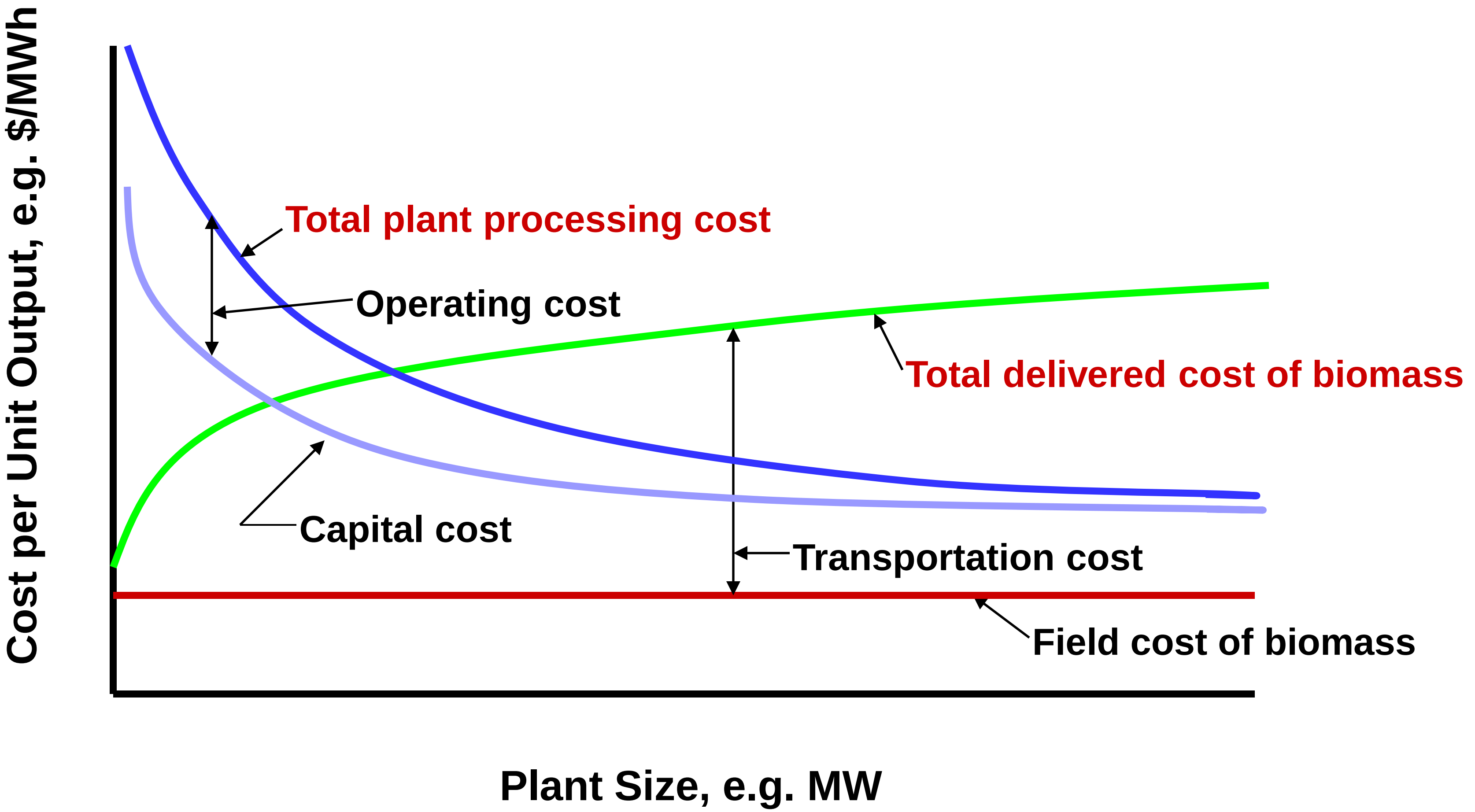
Cost Per Unit Output



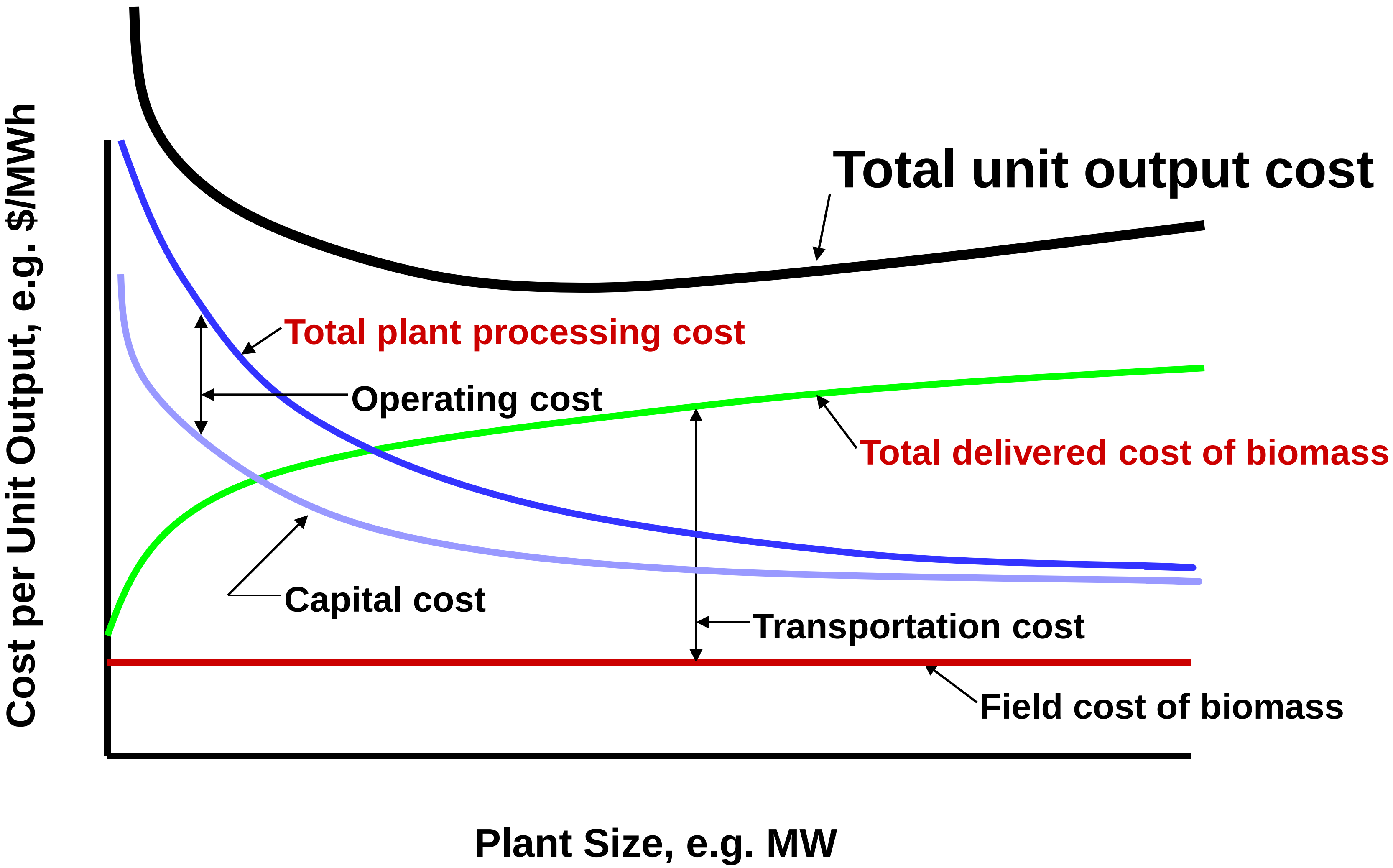
Cost Per Unit Output



Cost Per Unit Output



Cost Per Unit Output



Optimum Size

- Increases with increasing processing cost
- Increases with increasing biomass availability
- Is neutral to the field cost of biomass

50% of Optimum Size Has Minimal Impact, But the Cost Climbs Sharply Thereafter

- For example, power from straw in Alberta:
  - $75 per MWh at optimum (330 MW net)
  - $77 per MWh at 50% of optimum
  - $100 per MWh at 25% of optimum
  - $125 per MWh at 10% of optimum
  - $145 per MWh at 5% of optimum

Life Cycle Analysis of Emissions

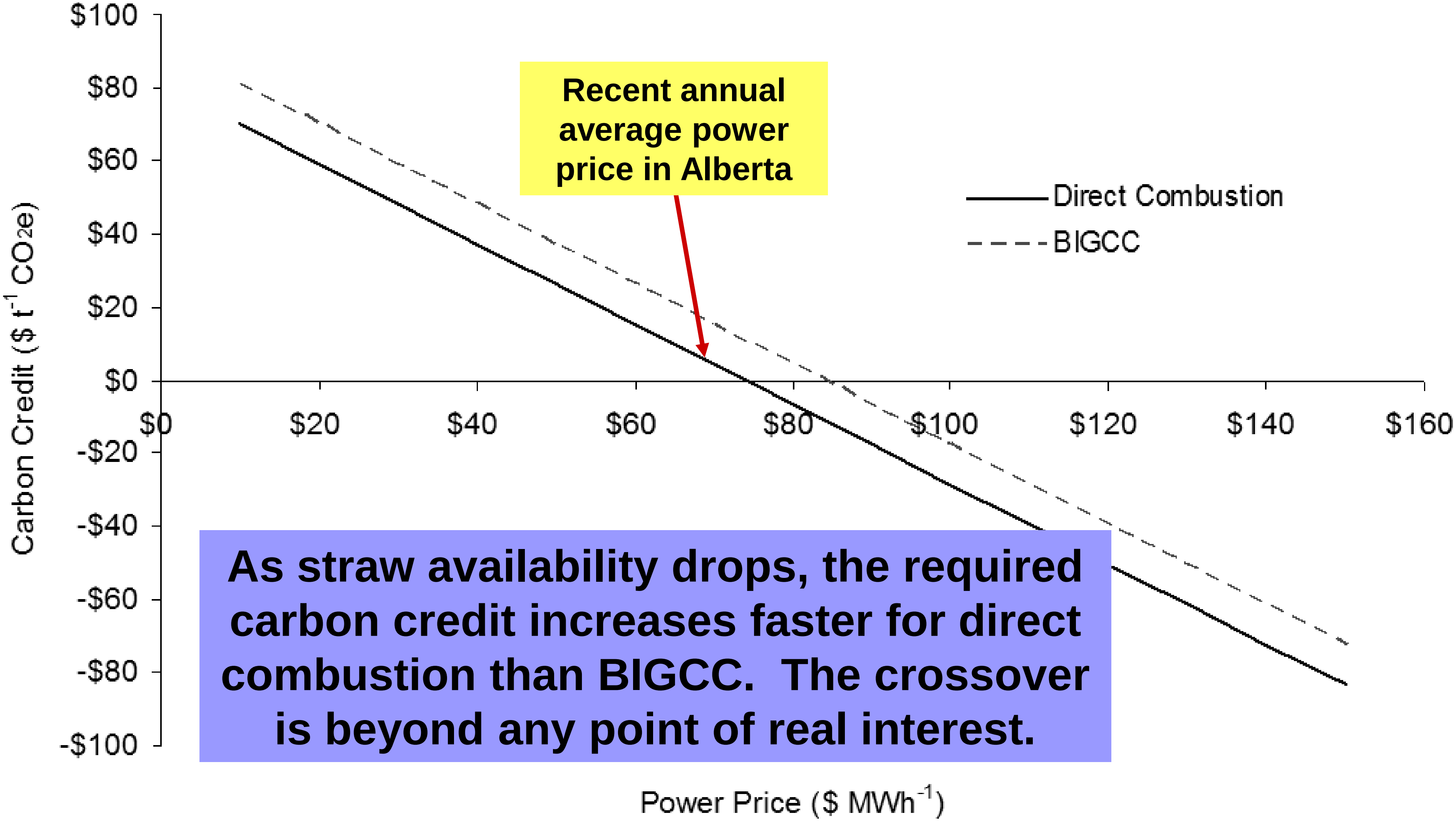
- For most biomass plants the replacement of fossil fuel is the overwhelming contributor.
- Processing related emissions tend to equalize, transport and refining are relatively small and estimates vary widely.
- Base load power vs. coal: 830 g/kWh.
- Ethanol and diesel: 2000-2400 g/l.

Two key process selection questions

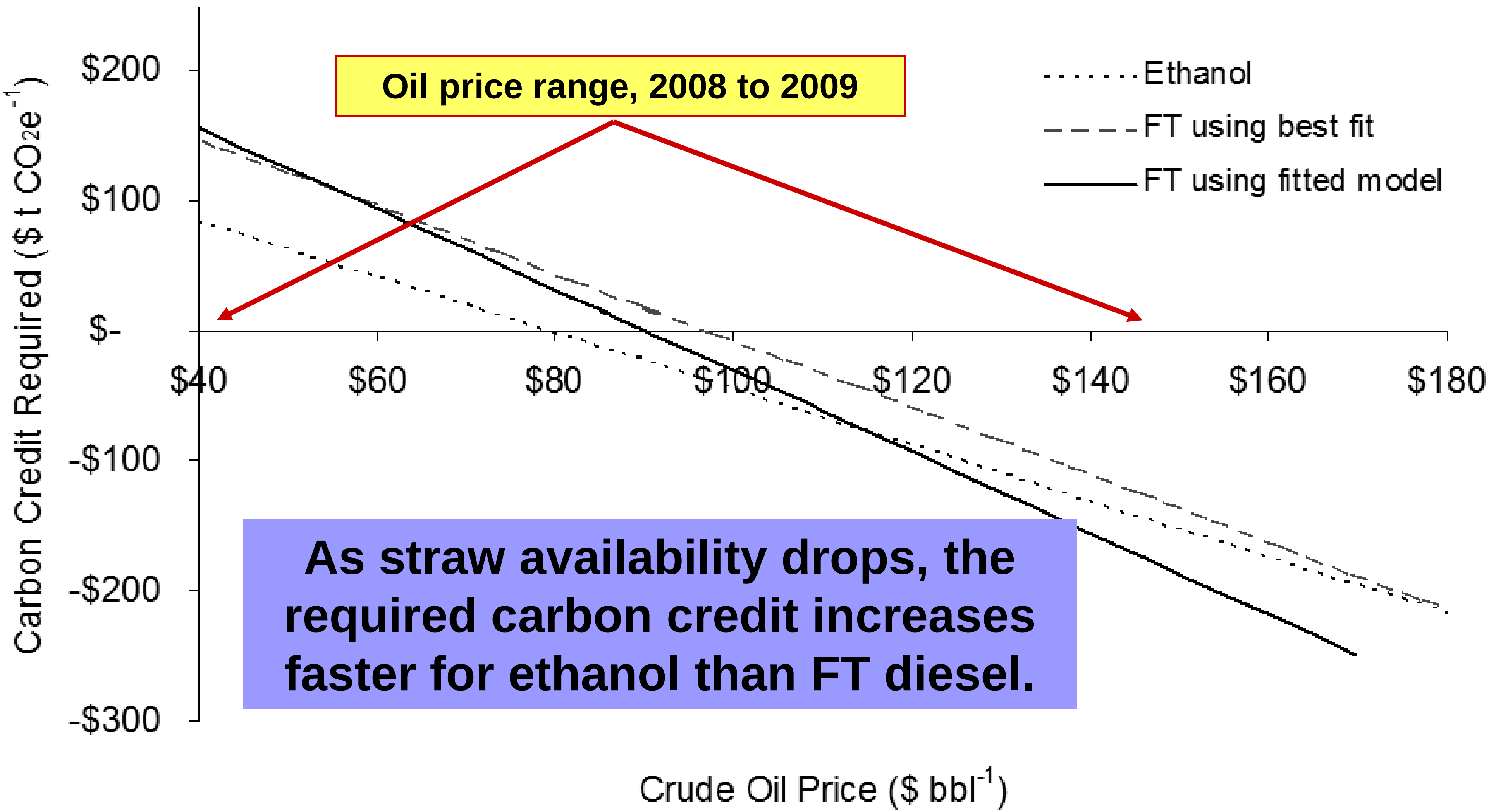
- For a given end form of energy, e.g. power or transportation fuel, what is the most efficient technology. (This will depend on the abundance of biomass, since low availability = higher delivered cost).

- Between two end forms of energy (fuel or power), what should I pick.

Gasification vs. Direct Combustion

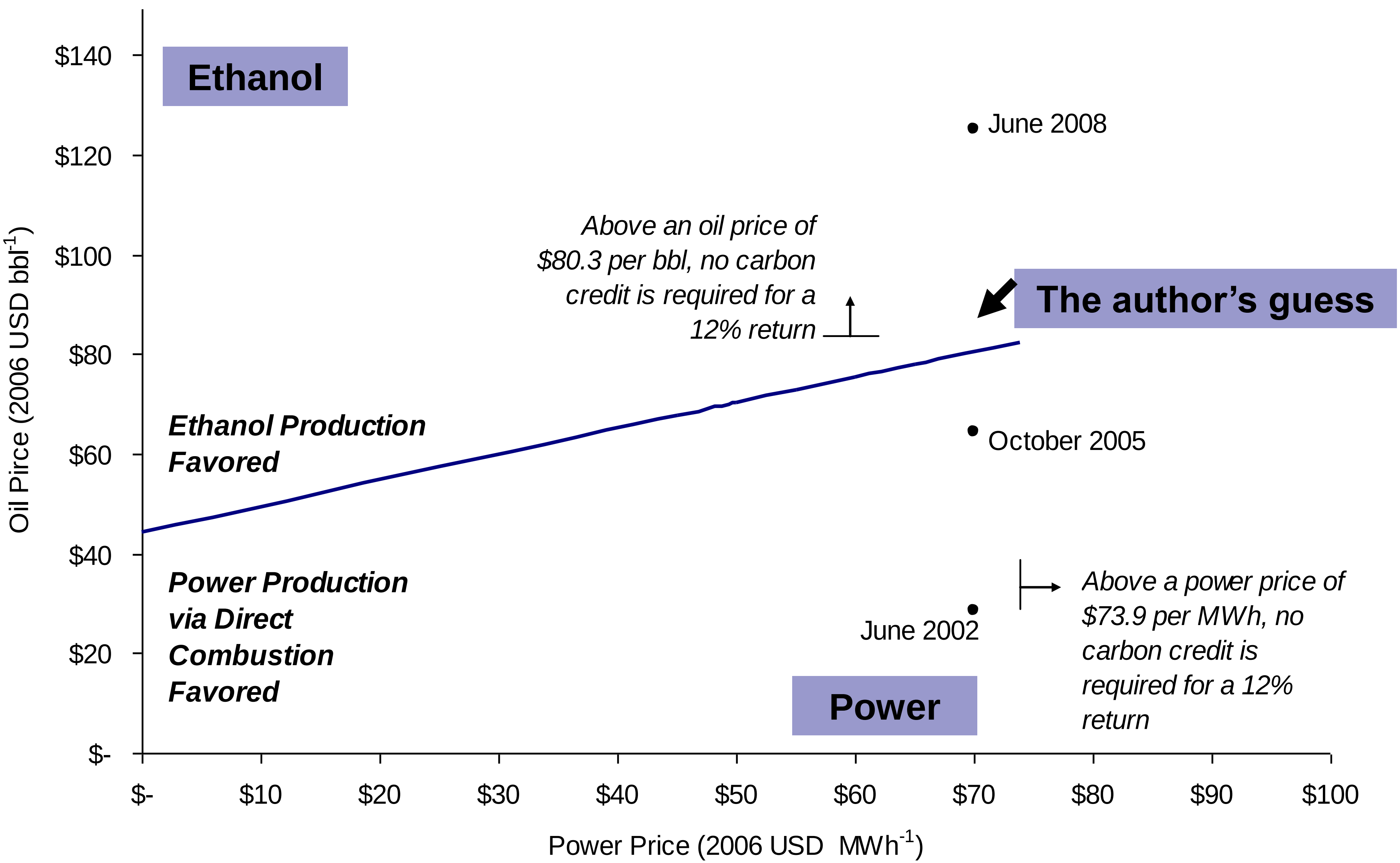


Ethanol vs. FT Diesel



As straw availability drops, the required carbon credit increases faster for ethanol than FT diesel.

Picking the End Energy Form



For Biomass Energy to Grow:

Drayton Valley, AB: 12 MW

Alholmens, Finland: 240 MW

Some Cautions

- Some technologies are far better demonstrated than others, hence more confidence in cost.
- All cost estimates rely on pre 2006 references, and hence miss the upswing in equipment and labor cost. The future of these costs is uncertain: have they swung down again?

	Ethanol	Fischer Tropsch	Direct Combustion	BIGCC
Optimum Size (dry t d^{-1})	8,250	16,250	5,750	14,250
Plant Size (dry t d^{-1})	4,000	8,000	2,875	7,000
Annual Output	416 ML	581 ML	209 MW_{gross}	623 MW_{gross}
Total Product Cost	\$0.40 L^{-1}	\$0.74 L^{-1}	\$59.6 MWh^{-1}	\$72.4 MWh^{-1}
Total Product Cost (\$ t^{-1} dry biomass input)	127	164	110	145

	Ethanol	Fischer Tropsch	Direct Combustion	BIGCC
Plant Size (dry t d^{-1})	4,000	8,000	2,875	7,000
Total Production Emissions[a] (g CO_2e)	-260 L^{-1}	650 L^{-1}	48.9 kWh^{-1}	44.3 kWh^{-1}
Avoided Emissions (g CO_2e)	2,060 L^{-1}	2,440 L^{-1}	837 kWh^{-1}	840 kWh^{-1}
Avoided Emissions (g CO_2e t^{-1} dry biomass input)	650	540	1,550	1,680