Economies of Scale for Biofuels Production

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Benefits of Scale

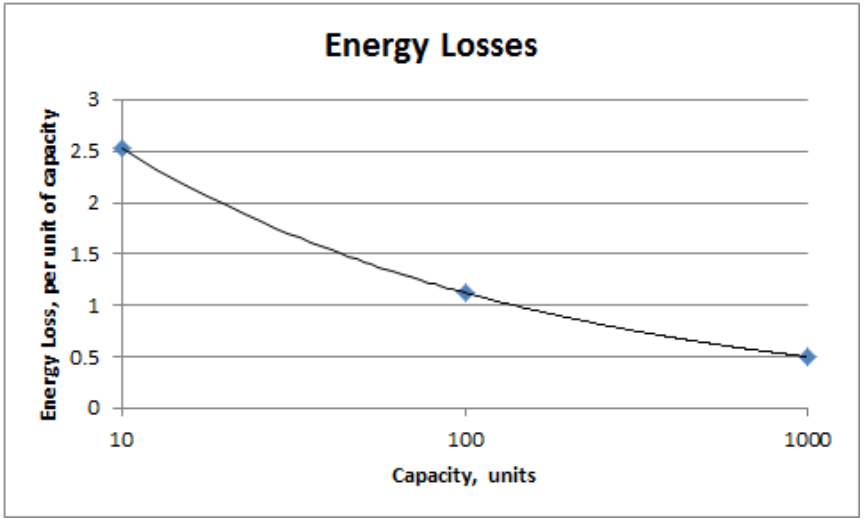
Unit product cost generally decreases with increasing plant size

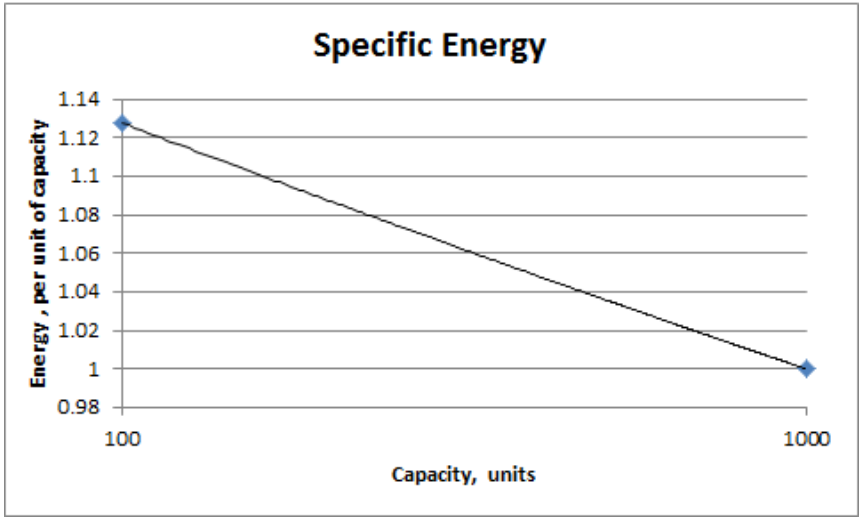
- Capital cost
  - Power law exponent < 1
- Efficiency
  - Proportionally lower losses at higher capacity
  - Shorter payback for high efficiency features on larger items
- Labor
  - Size of staff not proportional to capacity
- Monetization of byproducts
  - Larger scale enables investment to realize value that is otherwise lost – for example heat recovery steam generators

Efficiency and Scale

Fundamentals and economic tradeoffs both favor larger scale

Energy losses are a function of surface area, capacity is a function of volume – "square-cube law"





Specific energy includes both fundamental effects and capital/efficiency tradeoffs

Equipment and Plant Capital Scale Factors

The "6-tenths" power rule for scaling equipment and plant costs

- Rule is based on observation of how equipment and plant costs scale with capacity

$$\text{Cost} = \text{Cost}_0 \times (\text{Capacity}/\text{Capacity}_0)^x$$

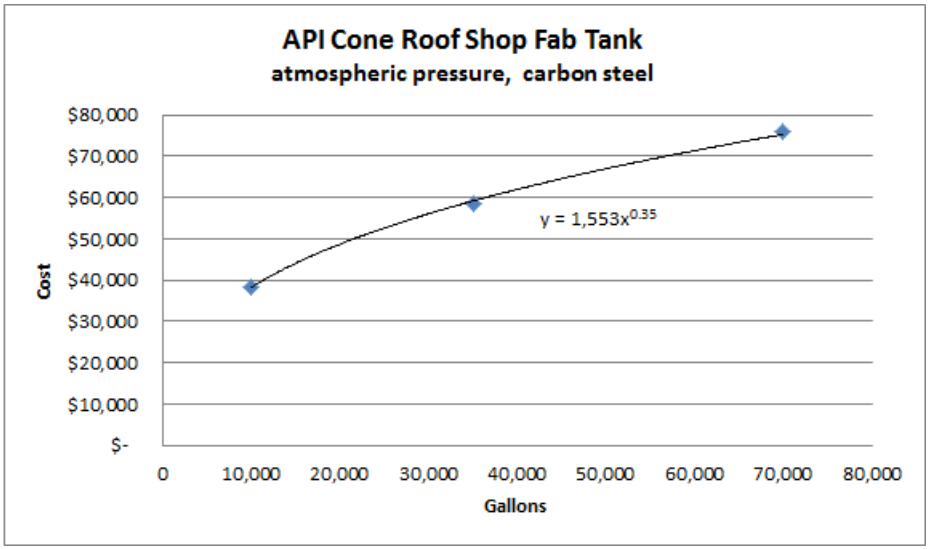
where:

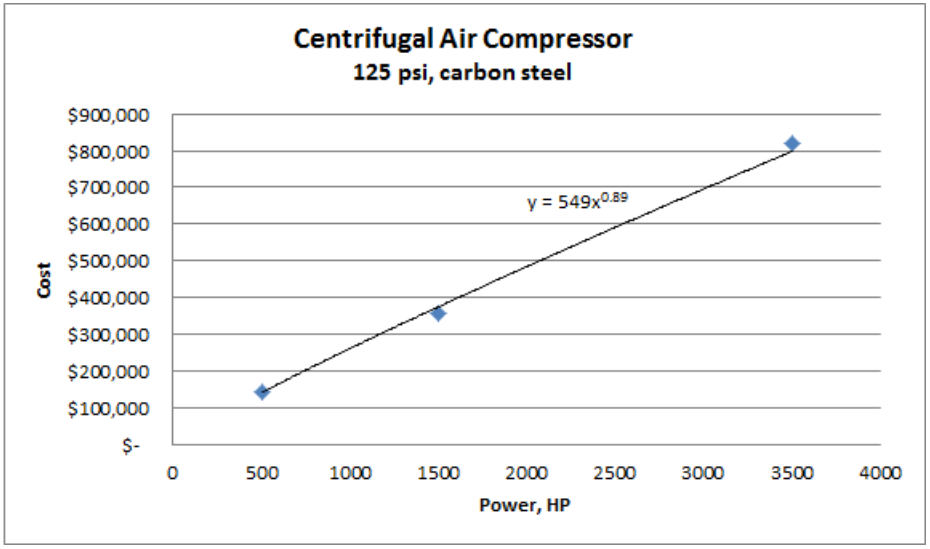
x = 0.3 to 0.8 for equipment (typical = 0.6)

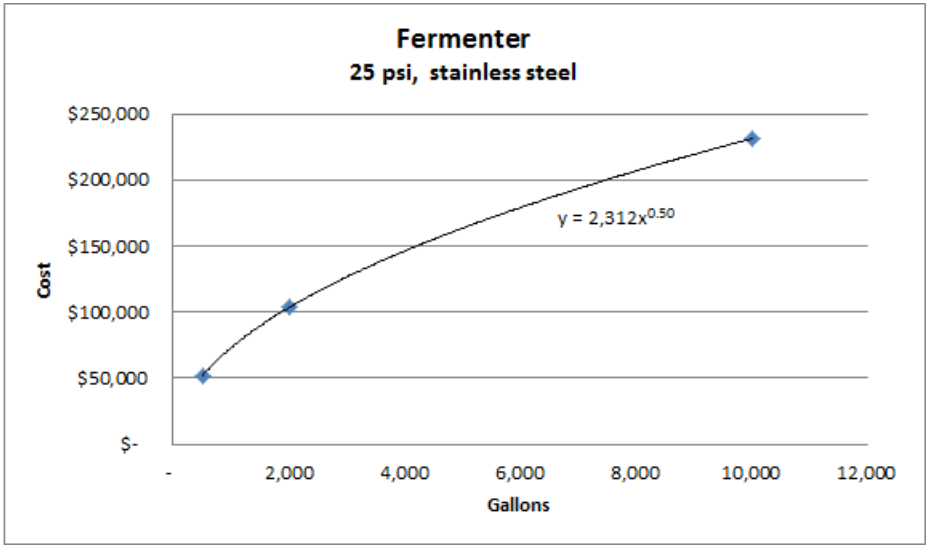
x = 0.4 to 0.9 for plants and process units (typical = 0.7)

- Why does it hold? Materials, engineering, fabrication and installation costs are not proportional to capacity

Examples of How Equipment Costs Scale







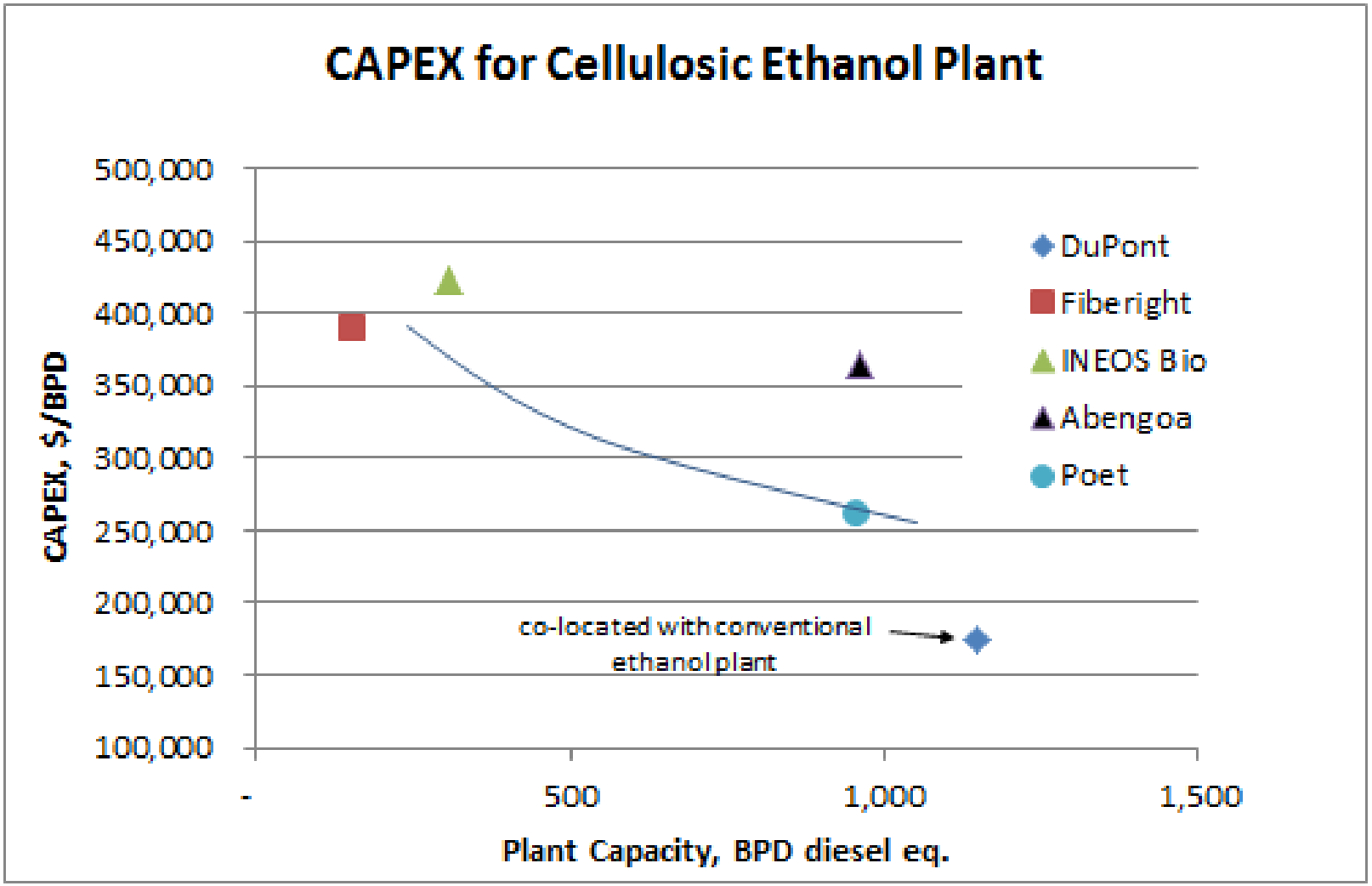
Reference: http://www.matche.com/EquipCost/

Capital Cost Break Points

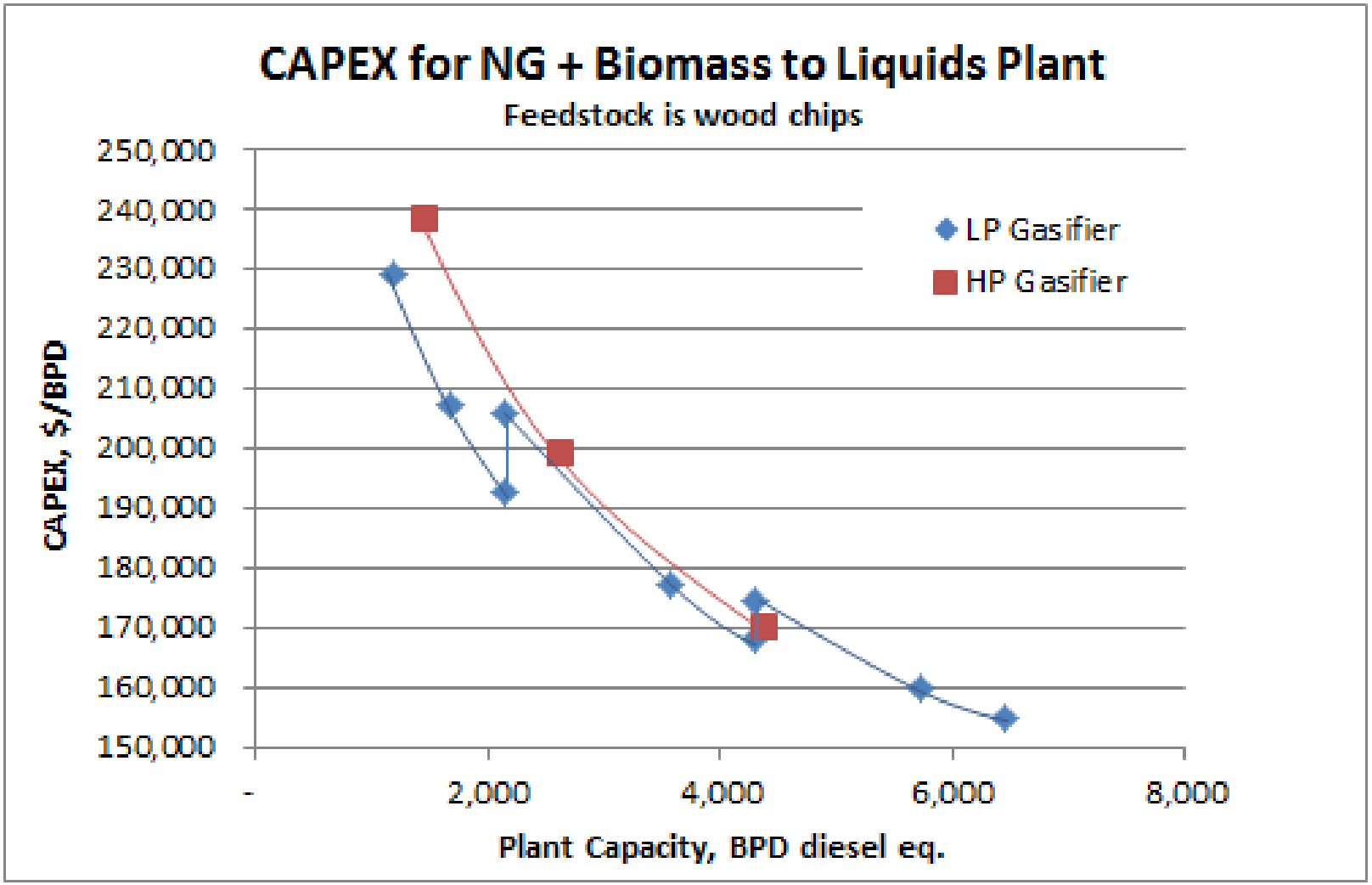
Disruptors of the “6-tenths power rule”

- **Materials limitations**
  - Maximum allowable stress
  - Columns and vessels
- **Shipping limits**
  - Weight and dimensional restrictions
  - Skids and assemblies
- **Frame sizes**
  - Discrete step changes in the size and cost of gear boxes, bearing, housings, etc.
  - Compressors, pumps and turbines
- **Shop vs. field fabrication**
  - Discontinuity driven by higher cost and low productivity of field fabrication

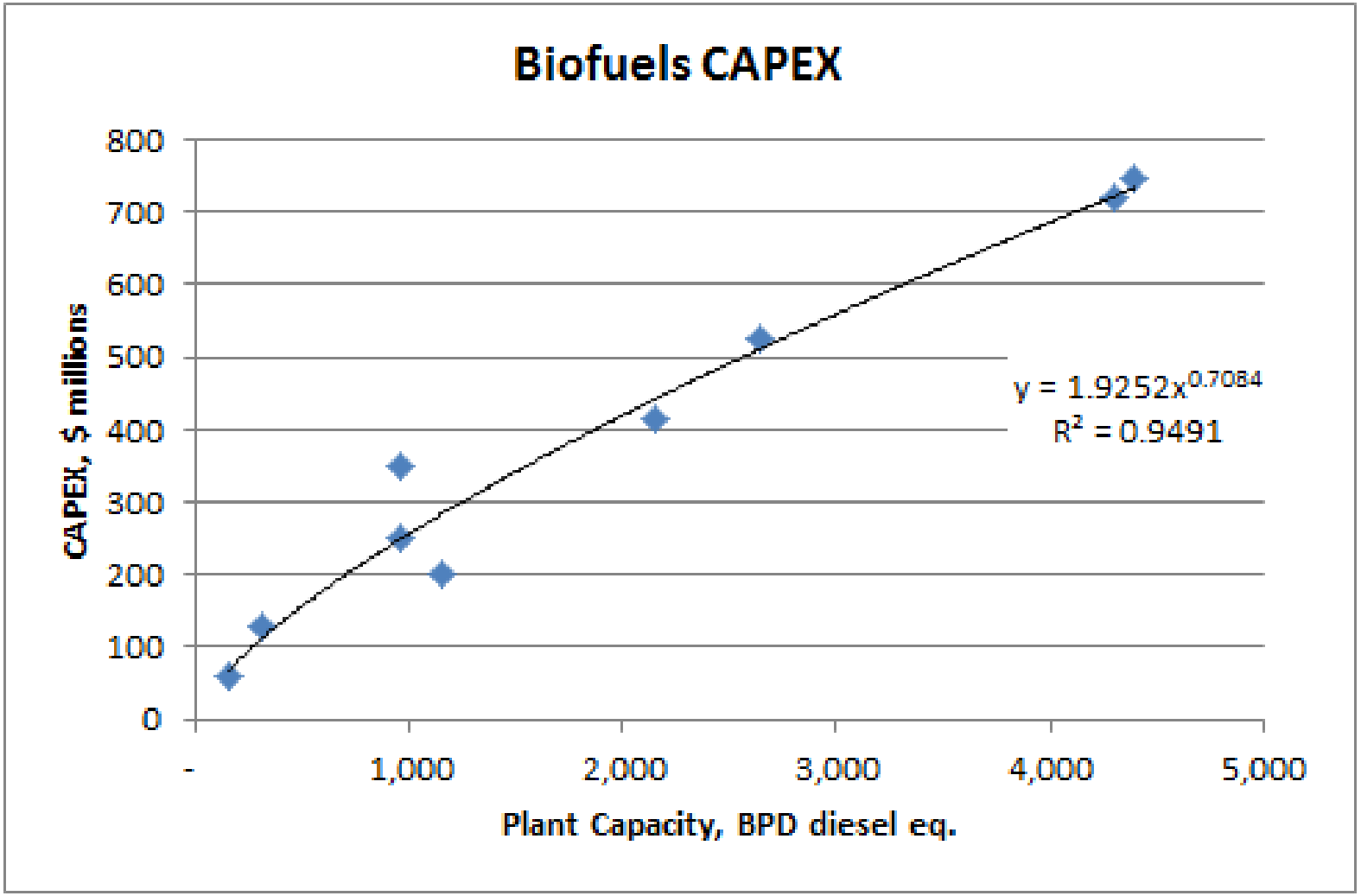
Cellulosic Ethanol Plant Cost Data



NG + Biomass to Liquids Plant Cost Data



CAPEX vs. Capacity



Achieving Nth Plant Costs

10 to 30% CAPEX saving vs. a one-off custom plant can be realized by:

- **Using standard equipment as much as possible**
- **Identifying and designing to key cost break points**
- **Designing for minimum field work**
- **Reuse of designs to minimizing engineering hours**
- **Developing standard modules**
- **Planning for multiple plants over time**
- **Implementing a procurement strategy that maximizes buying power**

Estimating Return on Investment

CAPEX per bbl/day of diesel eq.		
Input is capacity, bbl of diesel eq.		
$y = 1.9252*x^{0.7084}$		
Capacity, bbl/day	1	2,000
CAPEX, $ millions		419.7
CAPEX/capacity, $/bbl/day	2	**209,843**
Selling price of product, $/bbl diesel eq.		
Input is WTI benchmark crude oil price, $/bbl		
*y = 0.029*x +0.022*		
WTI, $/bbl		100
Diesel price, $/gal		2.92
Diesel price, $/bbl		122.72
Credit per gallon of diesel eq.		
Credit, $/gallon	3	1.00
Credit, $/bbl		42.00
Total product value = selling price + credit		
Product value, $/bbl		**164.72**

1. **Set the capacity in bbl/day of diesel equivalent based on lower heating value**
2. **Calculate plant CAPEX per bbl/day of capacity**
3. **Determine product value ($/bbl of diesel eq.) based on WTI benchmark price and applicable renewable fuels credits**
4. **Determine the required feedstock quantity and cost per bbl of diesel eq.**
5. **Calculate gross margin per bbl of diesel eq.**
6. **Payback in days = CAPEX ($/bbl/day) / gross margin ($/bbl)**
7. **Read IRR from chart**

Estimating Return on Investment

Energy content per bbl of diesel eq.		
LHV, Btu/gal		129,500
Enegy content, But/bbl		5,439,000
Feedstock to fuel conversion efficiency		
effieiency, LHV to LHV		40%
Required feedstock energy content.		
Btu/bbl of diesel eq.		13,597,500
Feedstock lower heating value	4	
Btu/ton		15,000,000
Feedstock required		
tons/bbl		0.91
Cost of biomass		
$/ton		40.00
$/bbl diesel eq.		**36.26**
Gross margin = selling price - cost of biomass		
$/bbl diesel eq.	5	**128.46**
Payback, days	6	**1,633**
IRR		**15%**