# Smaller Is Better
# Fostering Growth in the Biofuels Industry with Energy Manufacturing

Mark Mba Wright
Robert C. Brown
Mechanical Engineering
Iowa State University

Paul J. Componation
Industrial & Manufacturing Systems Engineering
Iowa State University

Advanced manufacturing and clean energy technologies are pillars of future economic development

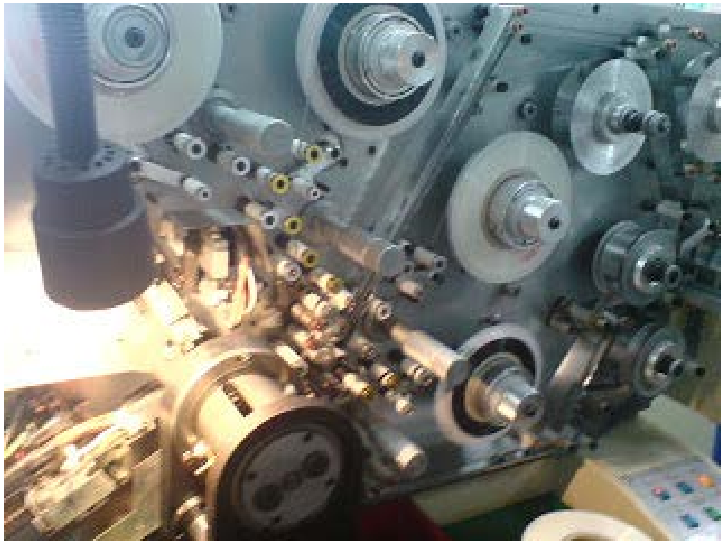
*--President Obama 2013 State of the Union*

Manufacture of energy conversion modules for distributed generation of renewable power

*--NSF Definition of* ***Energy Manufacturing***

# Energy Manufacturing Applied to Biorefining

- Concept for Distributed Biobased Manufacturing:
  - Manufacture of biomass processing modules for distributed conversion of biomass to biofuels and biobased products
- Attributes:
  - Mass production of processing modules
  - Procurement in quantity
  - Enhanced learning rates during manufacturing
  - Highly automated processing operations

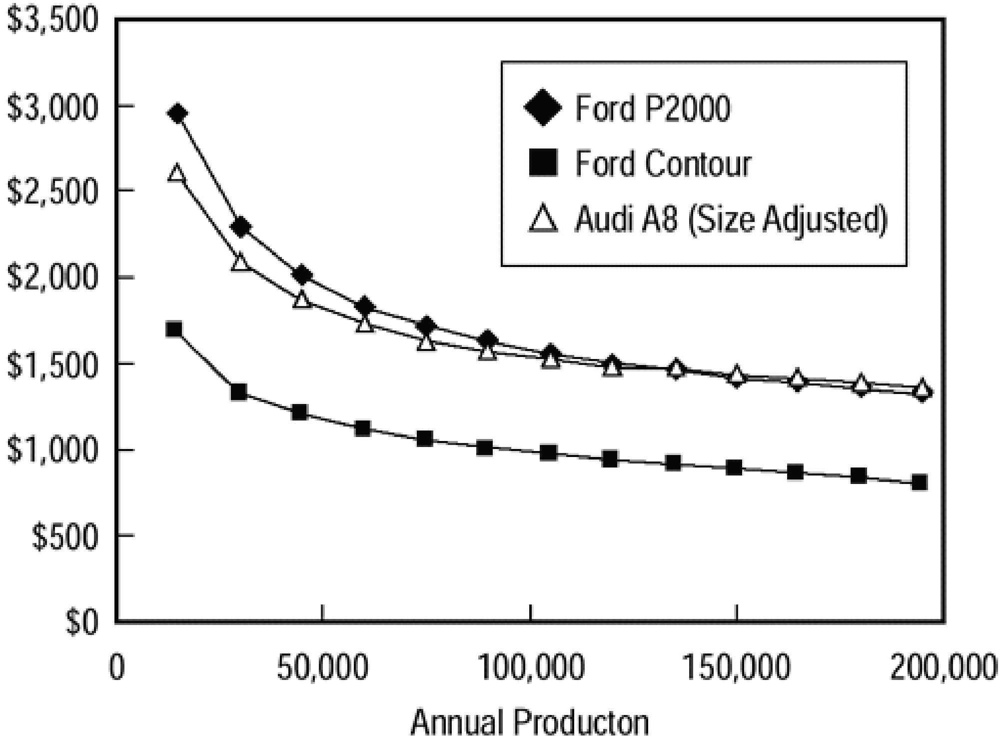


# Advantages of Distributed Biobased Manufacturing

| Conventional Biorefineries | Distributed Biobased Manufacturing |
|---|---|
| Large capital investments | Smaller capital investment |
| Long (years) deployment periods | Shorter deployment periods (months) |
| High technical and market risks | Lower project risks |
| Low learning rate – each facility is unique | High learning rate – accelerated by building multiple units |
| Complex feedstock supply logistics | Simpler supply logistics |
| Concentrated economic opportunity | Distributed economic opportunity |

# Mass Production of Processing Modules Could Achieve Similar "Economies of Scale" Of Single Large Plants

Mass Production Example from Manufacture of Automobiles

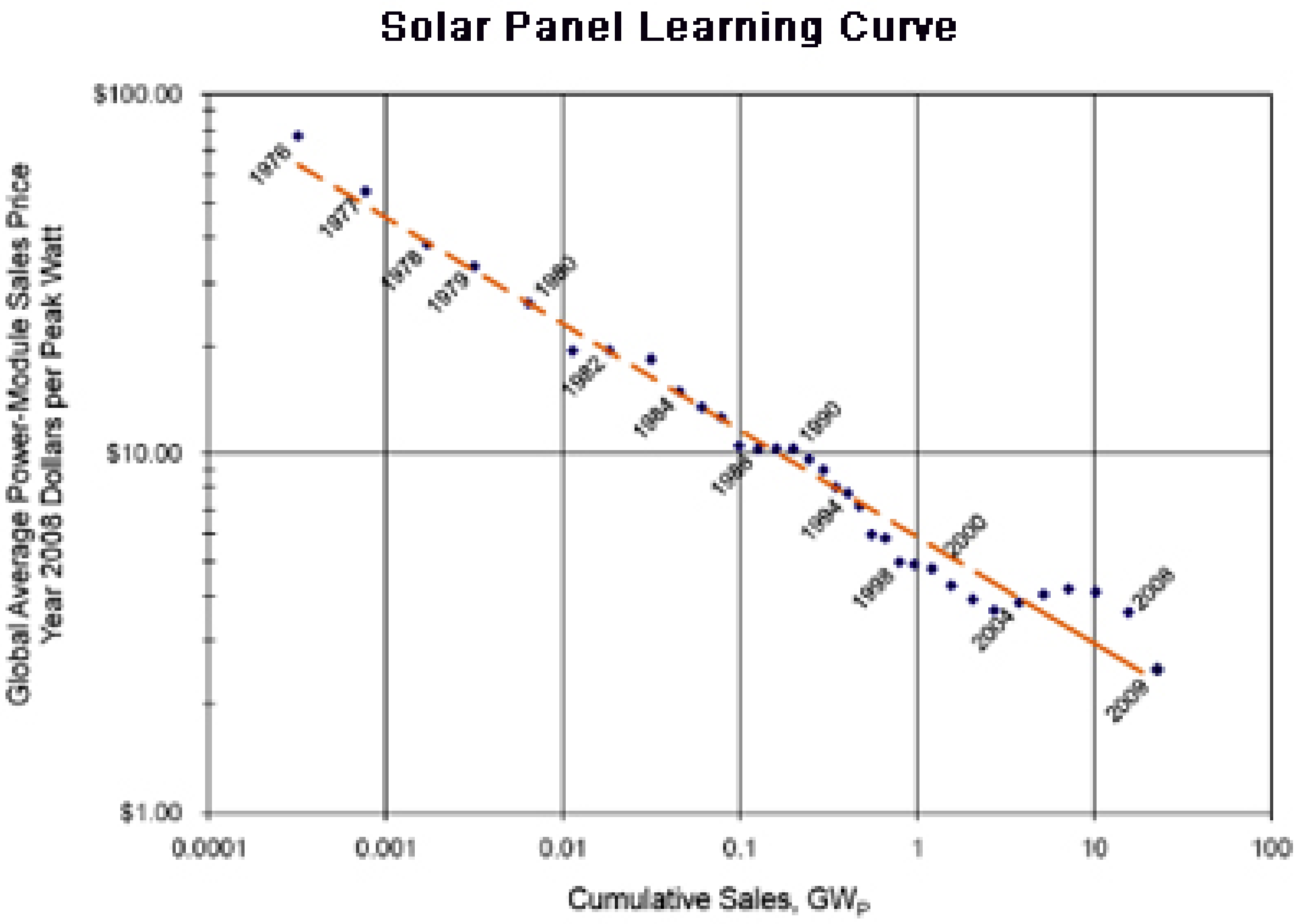


**Large processing plant economies of scale:**
Capital Costs proportional to (Plant Output)$^{0.66}$

**Mass production economies of scale:**
Capital Costs proportional to (Aggregate Output)$^{0.70}$

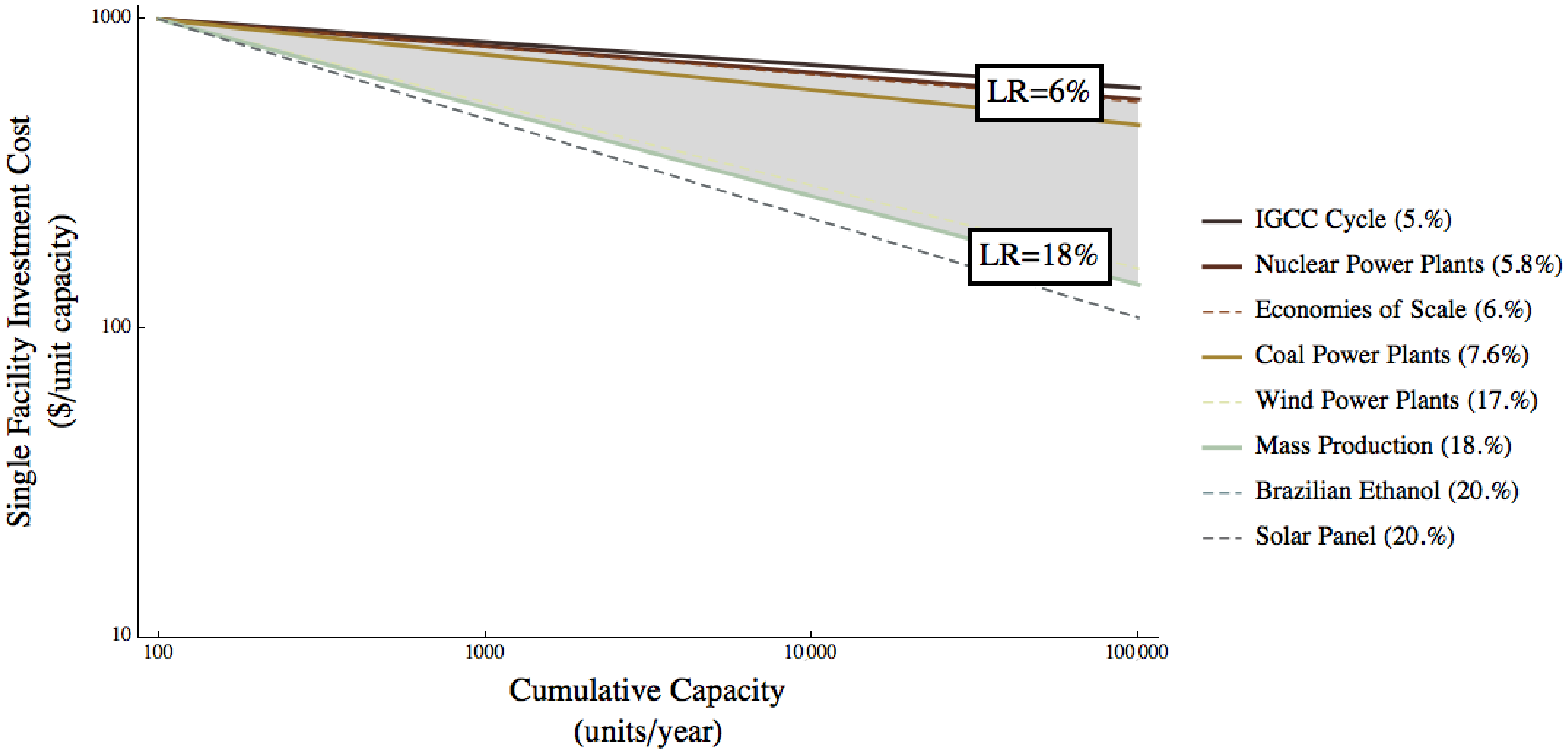
Source: A Kelkar, R Roth, J Clark. Automobile Bodies: Can Aluminum Be an Economical Alternative to Steel? JOM 53(8):28-32.2001

# Example from PV Solar Industry



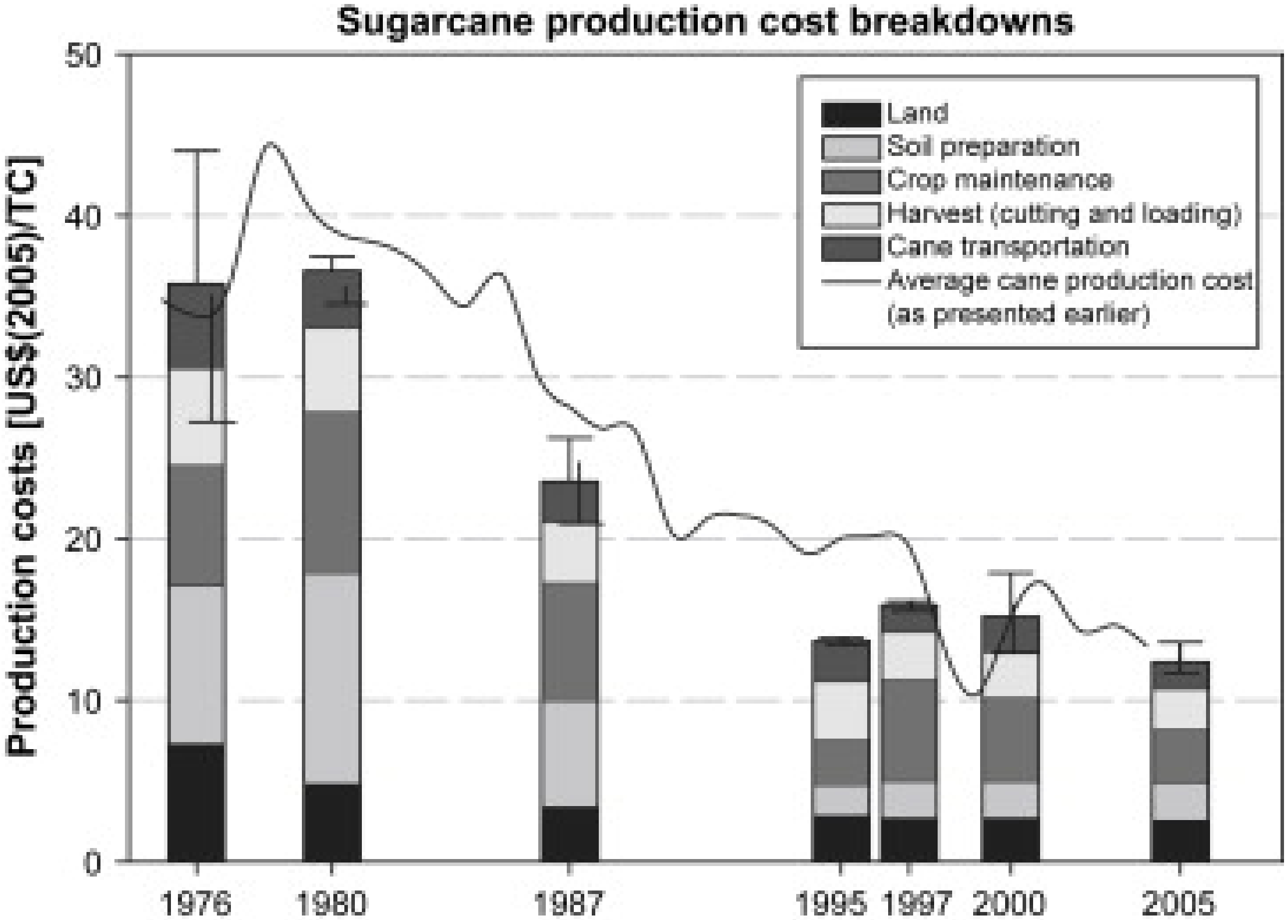
**Ken Zweibel, GWU**

# Examples Across Industries



Source: Adapted from McDonald and Schrattenholzer

# Impact of Learning on Brazilian Sugarcane to Ethanol Costs



Source: Van Den Wall Bake, J. D., Junginger, M., FAAIJ, A., Poot, T., & Walter, A. (2009). Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane. *Biomass and Bioenergy*, *33*(4), 644–658. doi:10.1016/j.biombioe.2008.10.006

# Impact of Learning on US Corn Ethanol Capital Costs

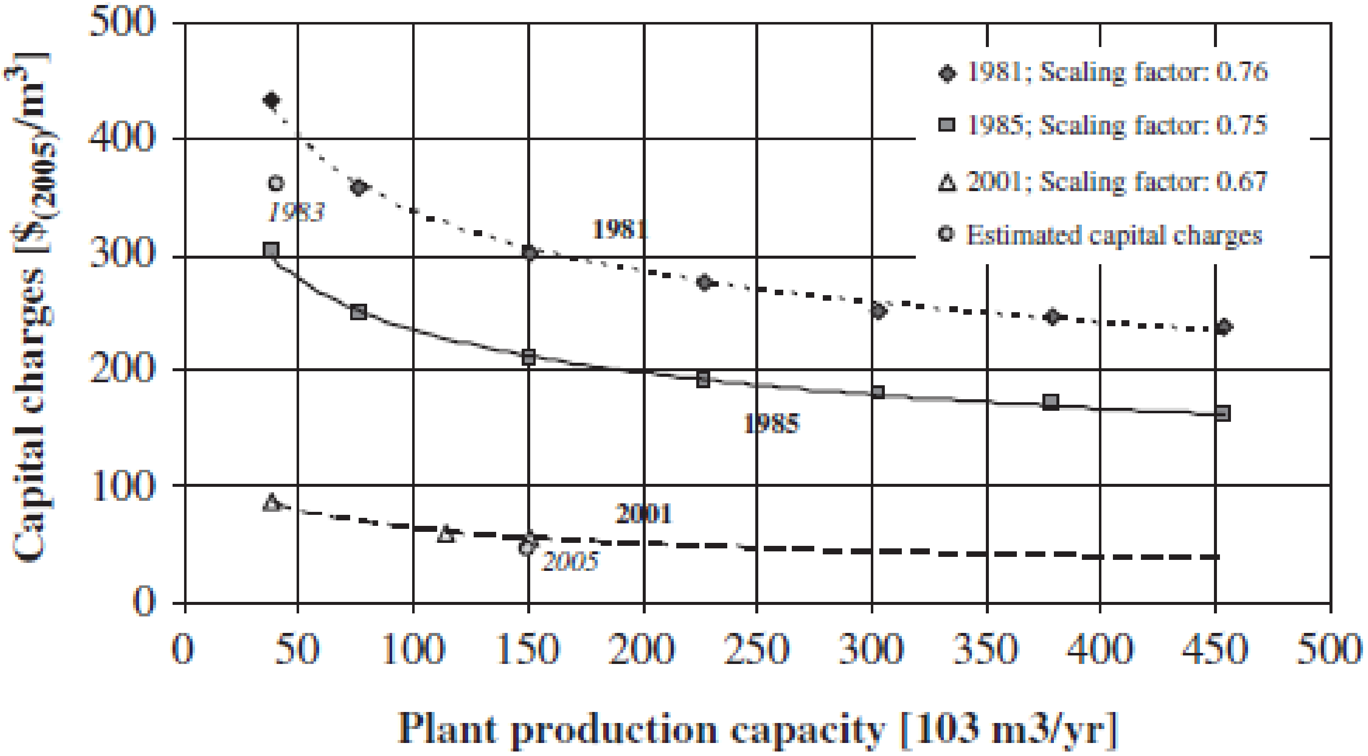
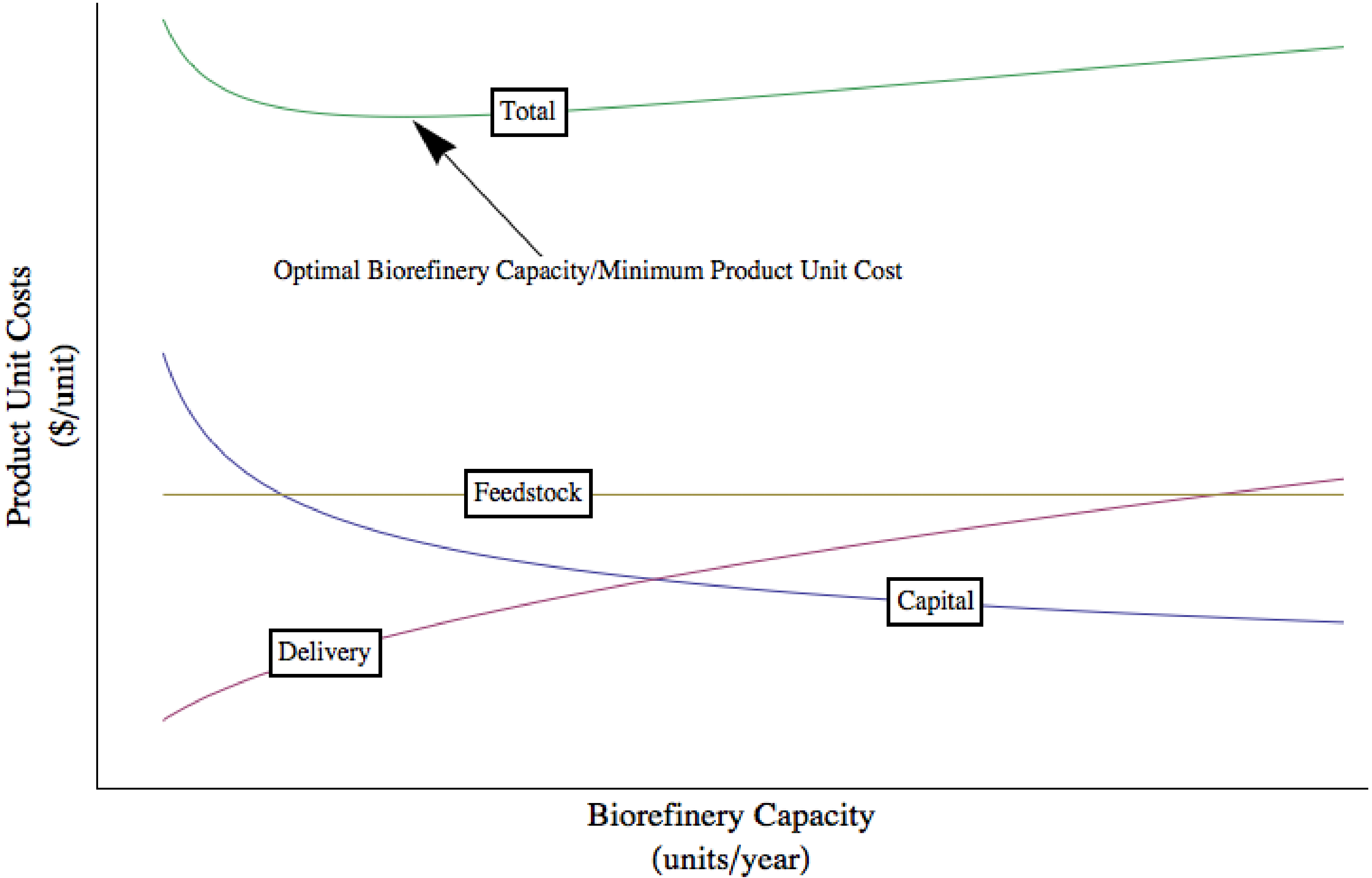


**Fig. 7.** Scaling factors for capital costs in different years. Capital costs have been reduced by upscaling, but even more by learning and other non-scale-related development. (*Data sources*: LeBlanc and Prato, 1982; Gavett et al., 1986; Whims, 2002).

Source: Hettinga, W. G., Junginger, H. M., Dekker, S. C., & Hoogwijk, M. (2009). Understanding the reductions in US corn ethanol production costs: An experience curve approach. *Energy Policy*.

# Scaling Relations for Biorefineries



Source: Daugaard T., Mutti L., Wright M., Brown R. C., Componation P. “Learning Rates and Their Impacts on the Optimal Capacities of Biorefineries” (In Press 2014) *Biofuels, Bioproducts & Biorefining*.

# Scaling and Learning Curve Relations

Economies of Scale:

$$C_T(M) = C_{Po}\left(\frac{M}{M_o}\right)^n + C_{Do}\left(\frac{M}{M_o}\right)^m + C_{Fo}\left(\frac{M}{M_o}\right)$$

Learning Curve:

$$C_t(M_t) = C_o M_t^{\log_2(1-LR)}$$

C (Capital Cost):

T (Total unit/facility); P (Plant/Investment); D (Delivery); F (Feedstock); O (Original)

M (Capacity):

t (Total industry/facility); O (Original)

n: facility capital scale factor; m: feedstock delivery scale factor;

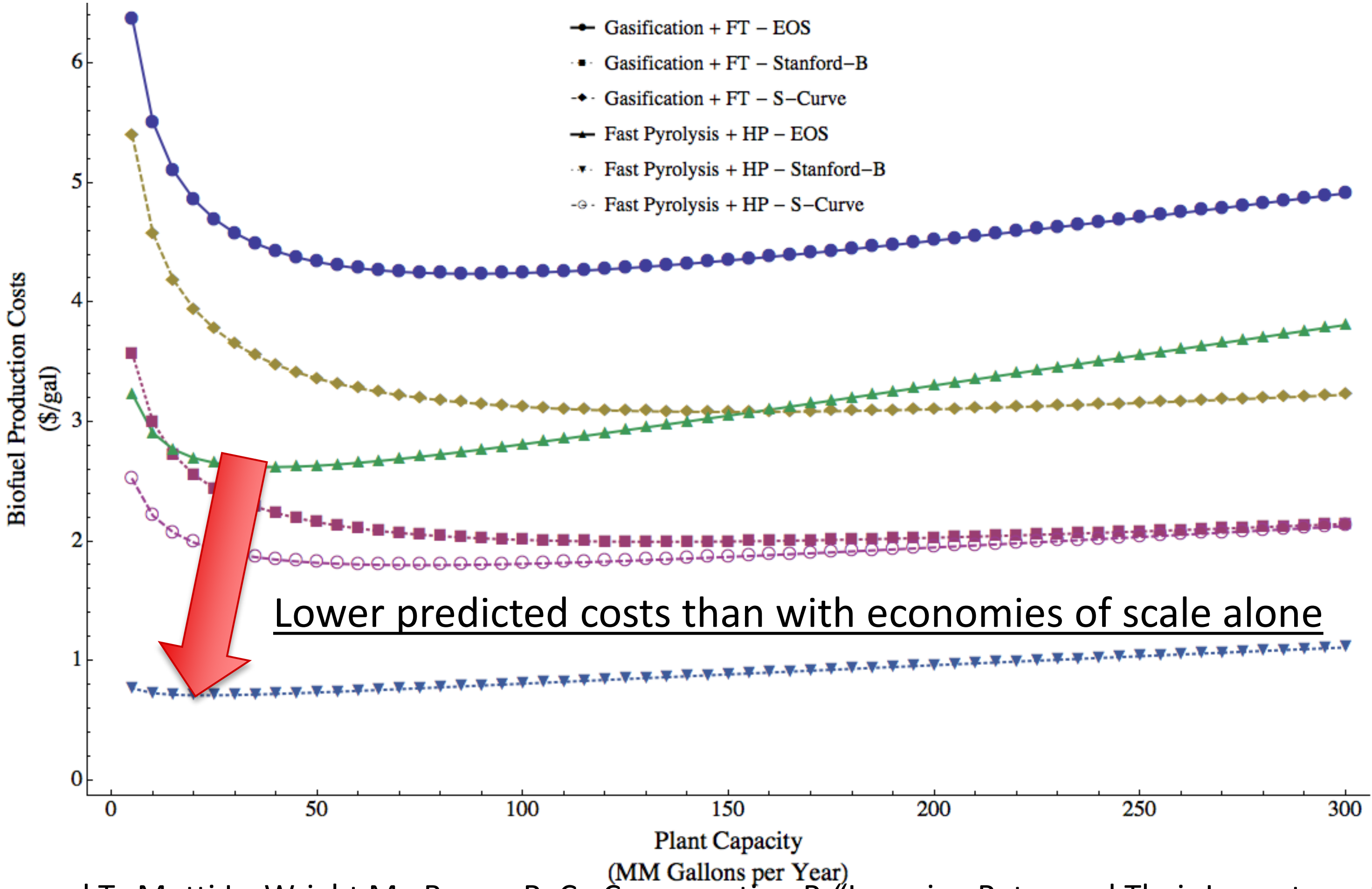
LR: Learning Rate

# Scaling Curve with Learning Effects

$$\underbrace{\frac{C_{po}}{M}\left(\frac{M}{M_o}\right)^{n}}_{\text{Scaling}}\underbrace{\left(\frac{M_t+B_o}{M_o+B_o}\right)^{\log_2(1-LR_p)}}_{\text{Learning}}$$

$B_O$: Prior Knowledge Factor (How many biorefineries has the industry built?)

# Case study: Gasification and Fast Pyrolysis



Lower predicted costs than with economies of scale alone

Source: Daugaard T., Mutti L., Wright M., Brown R. C., Componation P. "Learning Rates and Their Impacts on the Optimal Capacities of Biorefineries" (In Press 2014) *Biofuels, Bioproducts & Biorefining*.

# Research Findings

- Scaling curves with learning effects predict lower biofuel costs than economies of scale alone.
- Fast pyrolysis and grain ethanol platforms have smaller optimal capacities than other technologies.
- Smaller platforms have higher learning rates and a faster approach to lower costs.

Smaller facilities foster growth by:

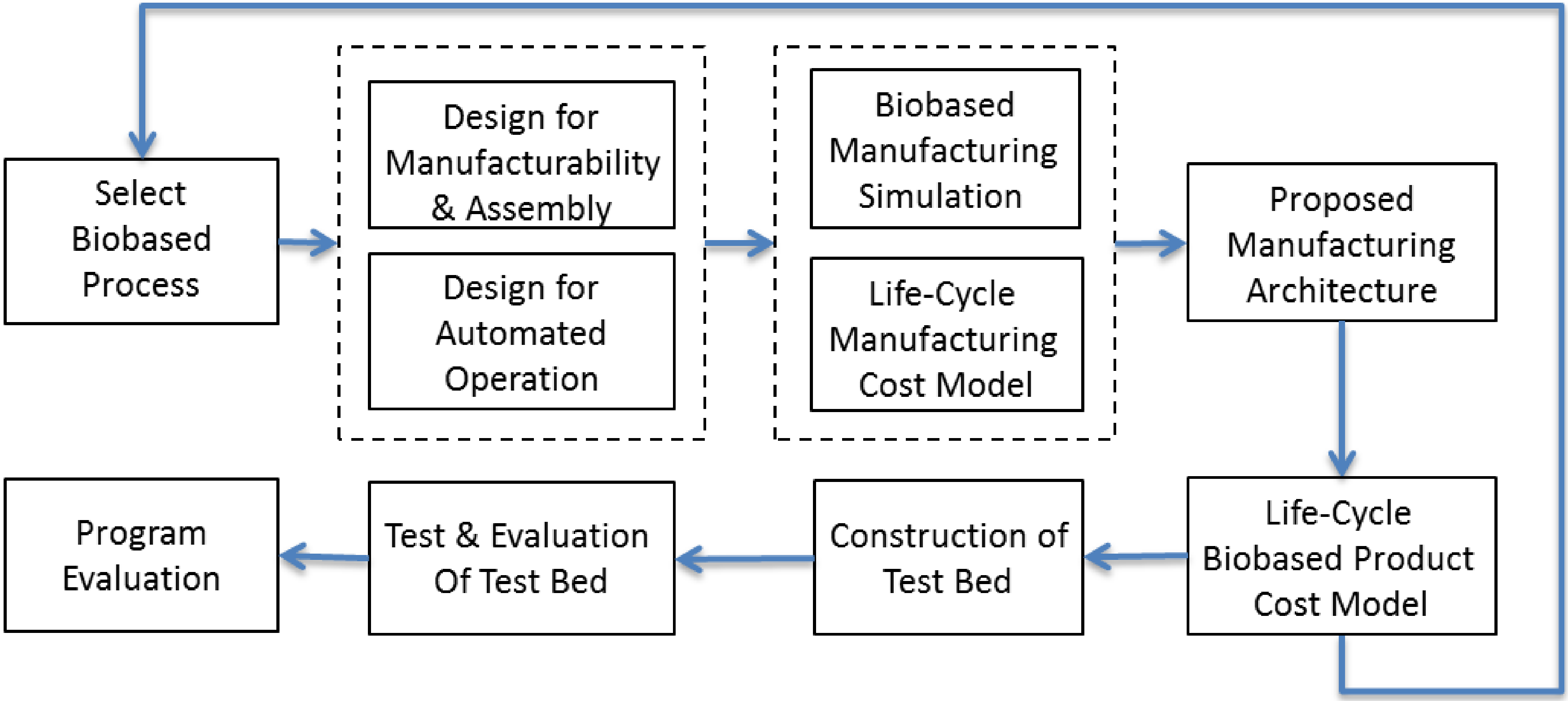
**Lowering** cost of entry

**Increasing** learning rates

**Lowering** overall biofuel costs

How can we benefit
the most from learning rates?

# Research Approach



Select Biobased Process

Design for Manufacturability & Assembly

Design for Automated Operation

Biobased Manufacturing Simulation

Life-Cycle Manufacturing Cost Model

Proposed Manufacturing Architecture

Life-Cycle Biobased Product Cost Model

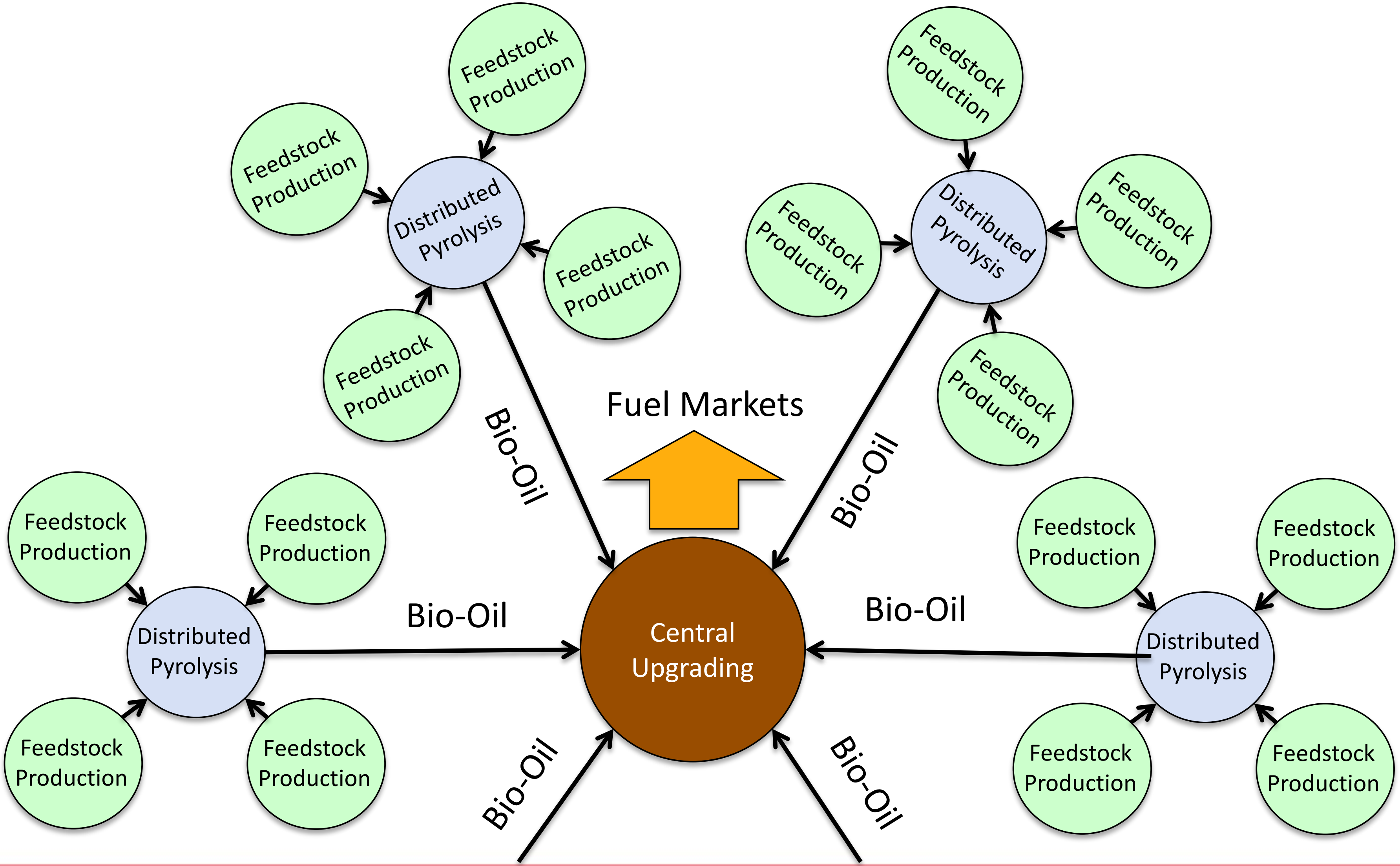
Construction of Test Bed

Test & Evaluation Of Test Bed

Program Evaluation

# Small and Distributed vs. Large and Centralized

# Distributed Processing Applied to Pyrolysis



# Acknowledgments

Biocentury Research Farm

IOWA EPSCoR
Building Sustainable Energy Systems

BEI
IOWA STATE UNIVERSITY