What is Sustainable Manufacturing?

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Outline

1. What is Sustainable Manufacturing?
2. Historical trends for efficiency and growth
3. What engineers can do

1. What is Sustainable Mfg?

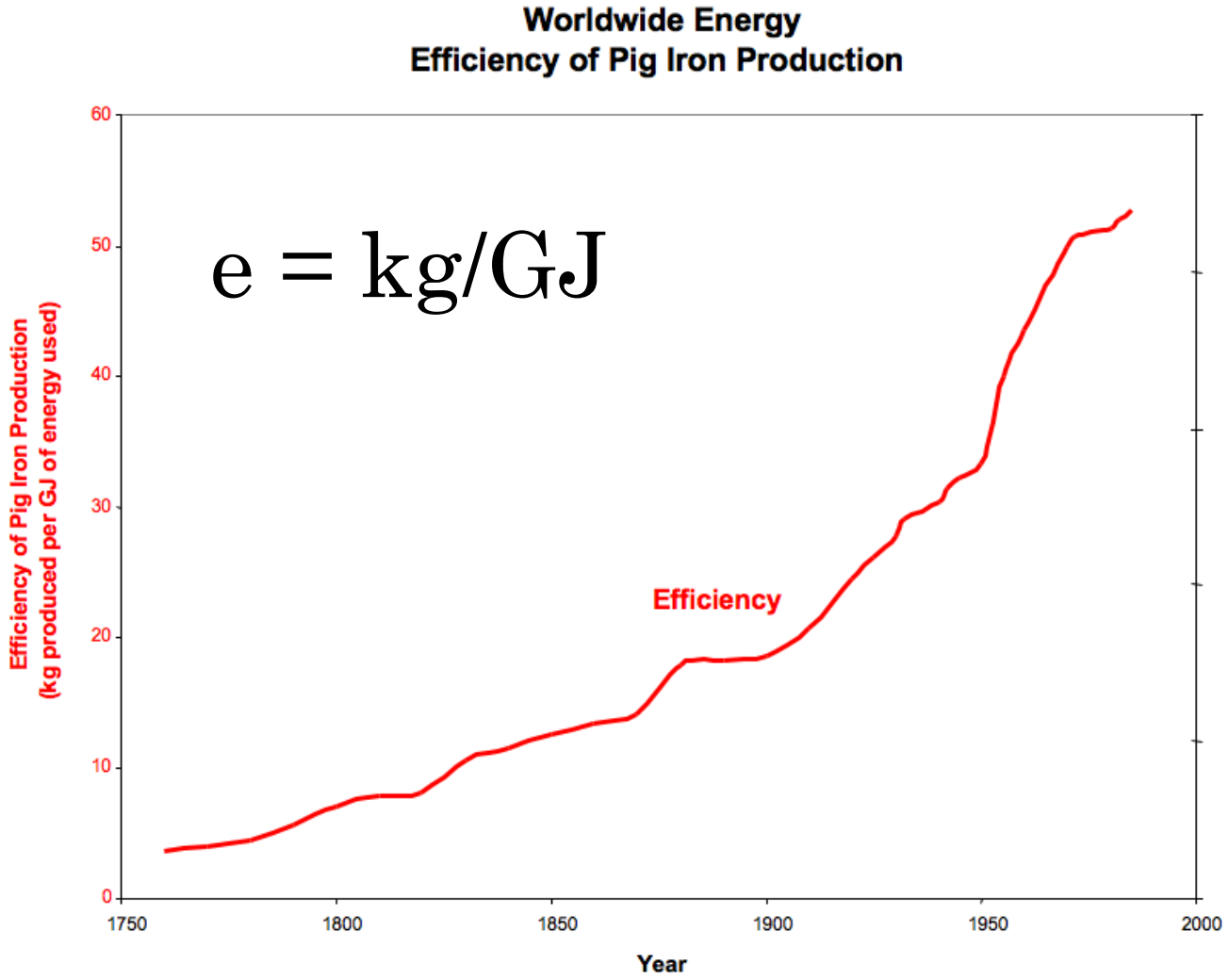
- What do the experts say…
- Barriers and Challenges
- Research Agenda for Sustainable Manufacturing

Connecting the two scales

Scale of the
Engineering action

Scale of sustainability

2. Historical pattern for energy efficiency in pig iron production



*Efficiency and Growth**

Activity	Dates	Boundary	Quantity	Resource
Pig-Iron	*1800-1990*	World	kg pig iron	Joules of coke
Aluminum	*1900-2005*	World	kg aluminum	Joule of electricity
Nitrogen Fertilizer	*1915-2000*	World	kg Nitrogen	Joule energy
Electricity from coal	*1920-2007*	US	Joule electricity	kg coal
Electricity from Oil	*1920-2007*	US	Joule electricity	Liter of oil
Electricity from Natural gas	*1920-2007*	US	Joule electricity	m^3 of natural gas
Freight Rail	*1960-2006*	US	Revenue tonne- km	Liter fuel
Air Travel	*1960-2005*	US	Seat-km	Liter fuel
Motor vehicle	*1936-2006*	US	Vehicle – km	Liter fuel
Refrigeration	*1960-2002*	US	Hours refrigeration	Joule electricity

* Dahmus, Gutowski 2012

FIGURE 1: Pig Iron Production (*Q*) and the Efficiency of Pig Iron Smelting (*e*) (World) [a]

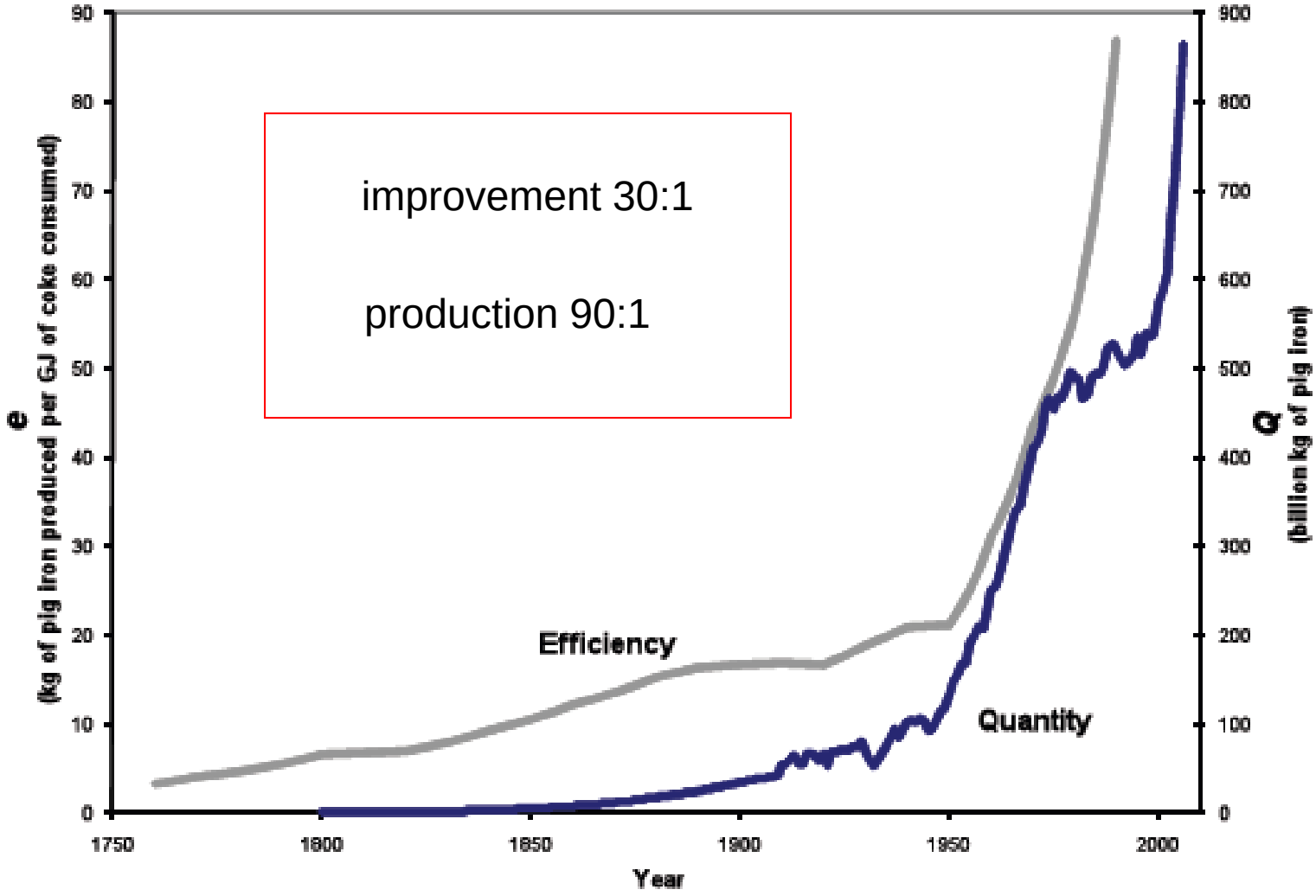


FIGURE 2: Primary Aluminum Production (*Q*) and the Efficiency of Aluminum Smelting (*e*) (World) [b]

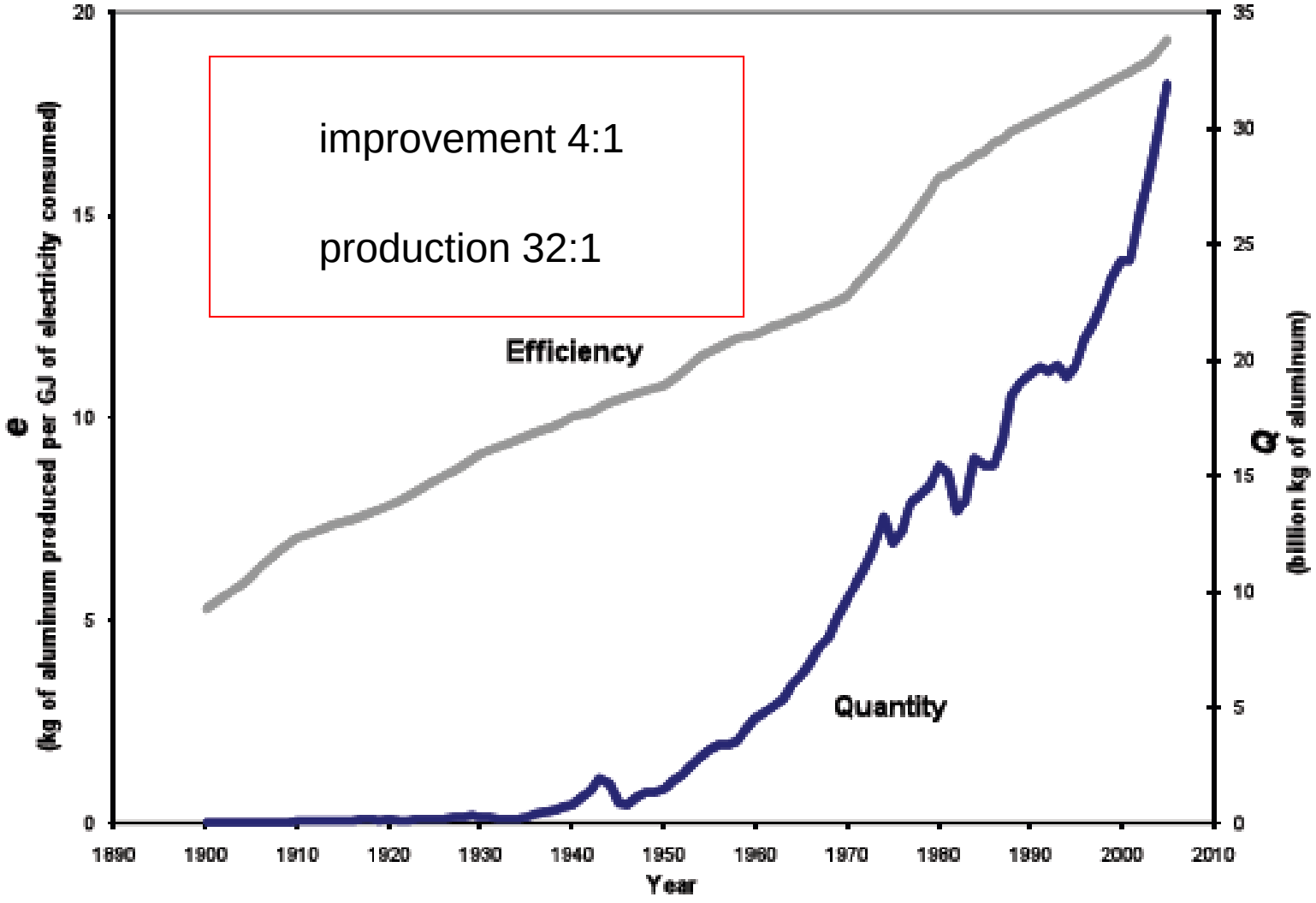
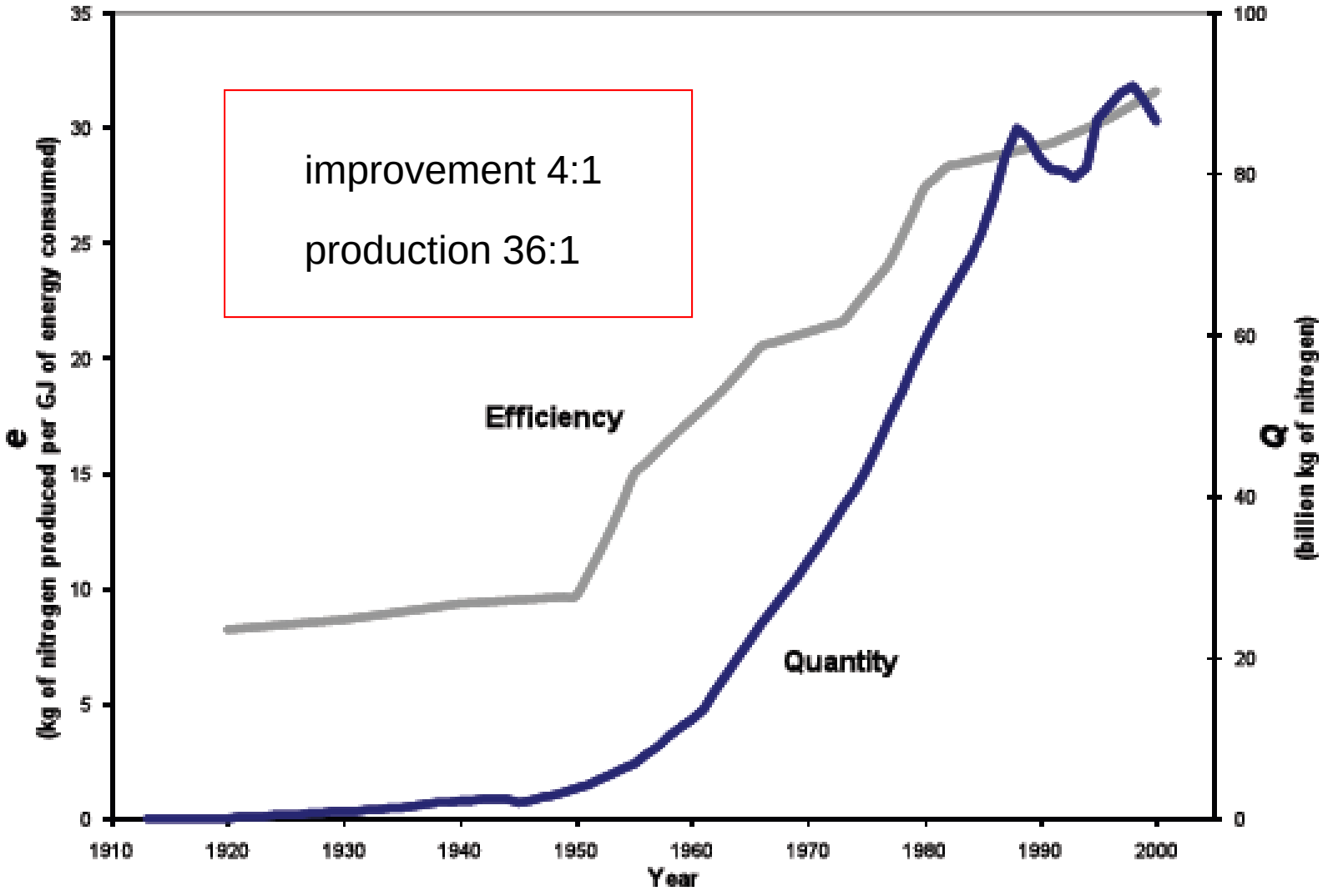


FIGURE 3: Nitrogen Fertilizer Production (*Q*) and the Efficiency of the Haber-Bosch Process (*e*) (World)[c]



Average annual ΔQ/Q versus average annual Δe/e

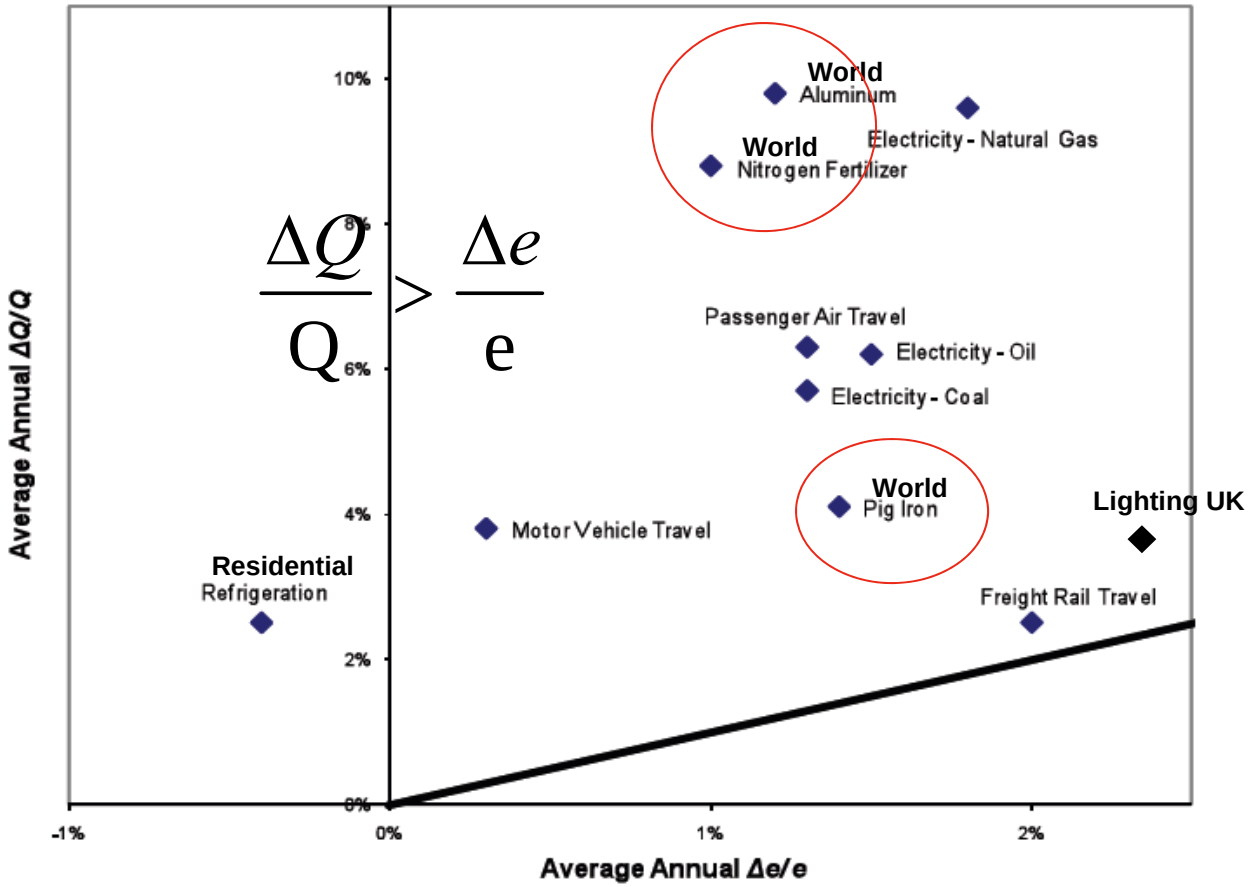


Figure 11: Average annual *ΔQ/Q* versus average annual *Δe/e* for ten activities. The solid diagonal line is the line of constant resource consumption, representing the condition in which the average annual *Δe/e* is equal to the average annual *ΔQ/Q*.

What is going on?

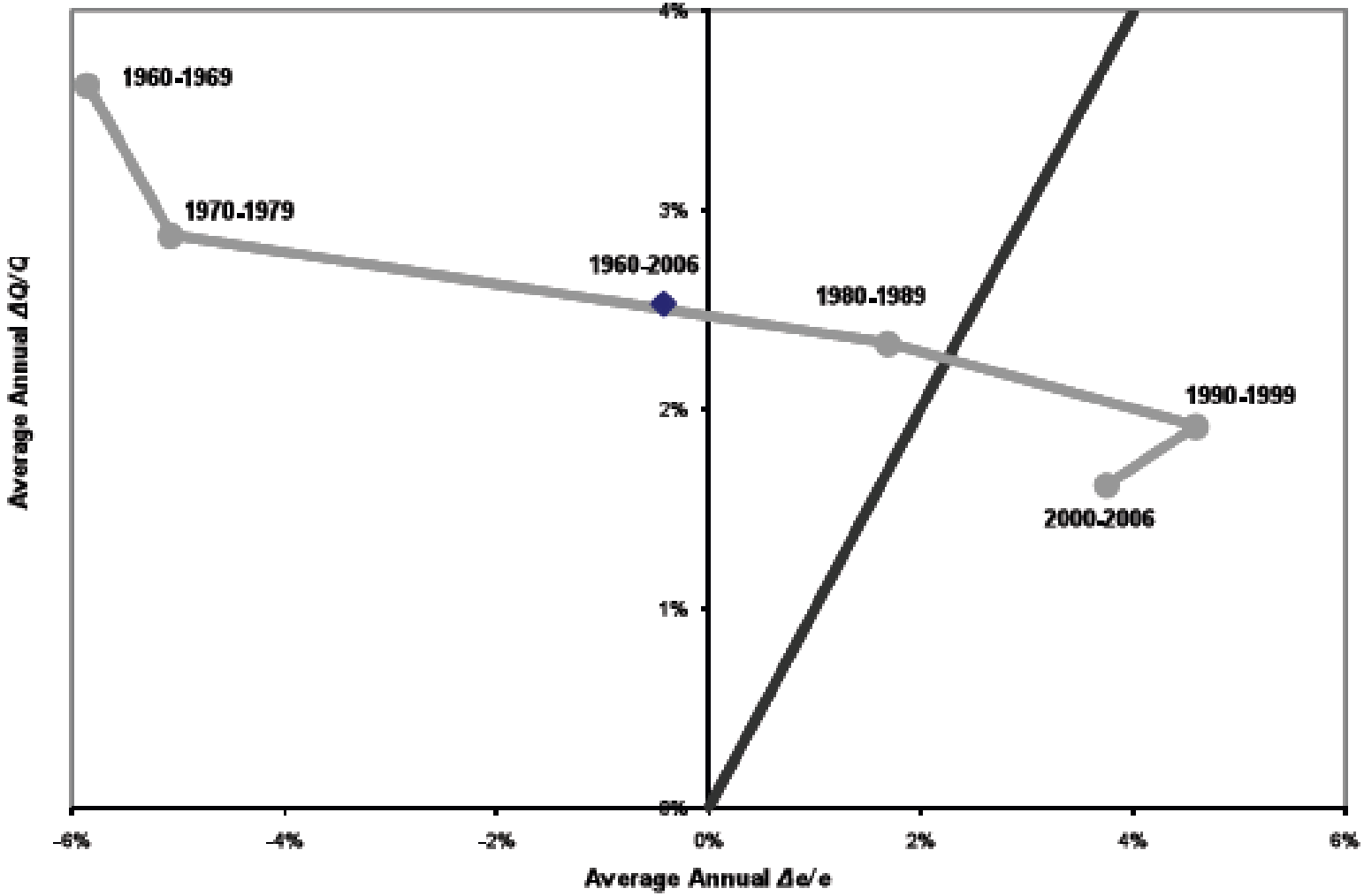
- Human Behavior -

  People do what they want to do.
  - Consumers want to satisfy their needs and to procreate
  - Producers want to make a profit and expand their market share

However,

- *Examples when efficiency outpaced demand*
  - pig iron 1970 – 1989
  - freight rail travel 1980 – 1989
  - passenger air *almost 1970 – 1979*
    and almost again 2000 – 2007
  - *passenger autos came close 1980 - 1989*
  - *refrigeration 1990 - 2006*

FIGURE 18: Average Annual $\Delta Q/Q$ versus Average Annual $\Delta e/e$ for Refrigeration (US data)[h]



Why are refrigerators different?

- Saturation in demand, but

Why are refrigerators different?

- Saturation in demand, but…

Why are refrigerators different?

3. What Engineers Can Do

1. After all, we are engineers…
2. New Analysis Models & Data
3. Make Sustainability Fun

We are engineers..

- The “existence proof”

  Vs

- Business as Usual (BAU)

Opportunities for Efficiency

Heavy Industry

Housing

Autos

$$\eta = \frac{\text{services delivered}}{\text{resources used}}$$

*The Existence Proof**

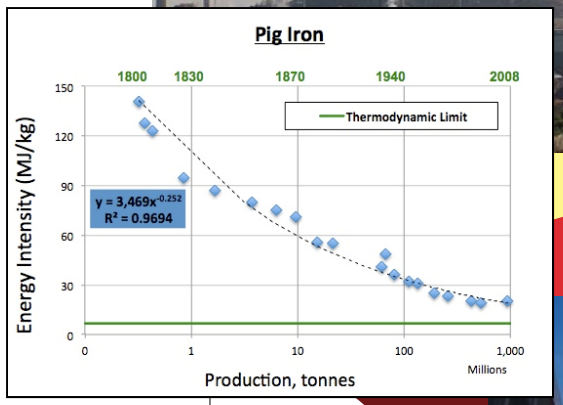
Integrated Steel Mill
19MJ/kg

*Passivhaus
15kWh/m2

*VW XL1
260 mpg

Improvement Ratios

Integrated Steel Mill
2:1



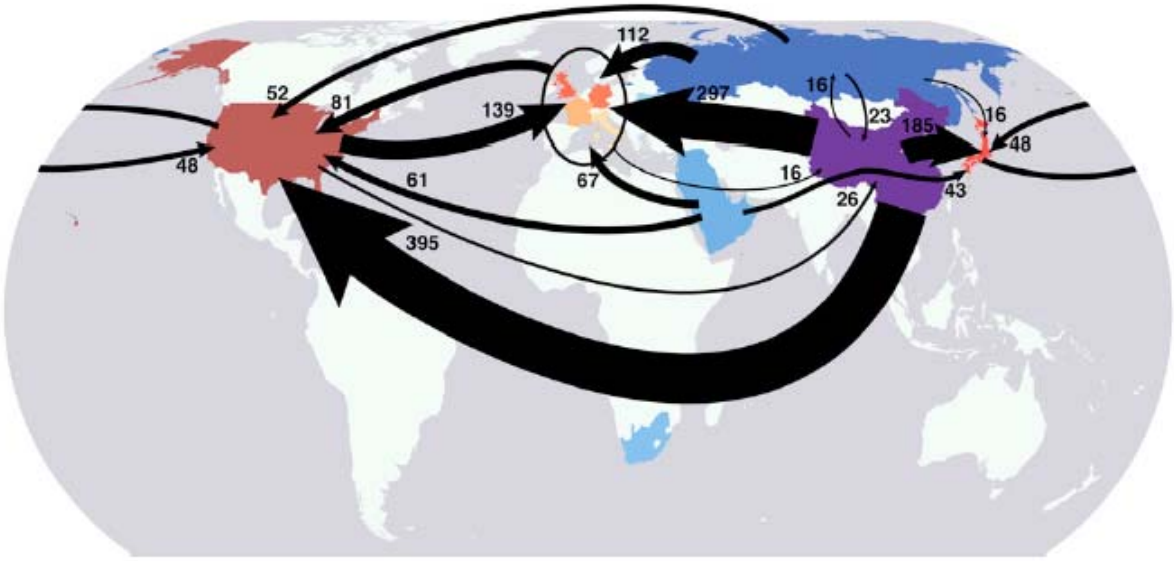
Heating
8:1

Buildings
Transport
Mfg

Mileage
8:1

New Analytical Tools

- Global Flows of Energy & Materials
- Multiregional Input/Output Models
- Consequential Life Cycle Assessment



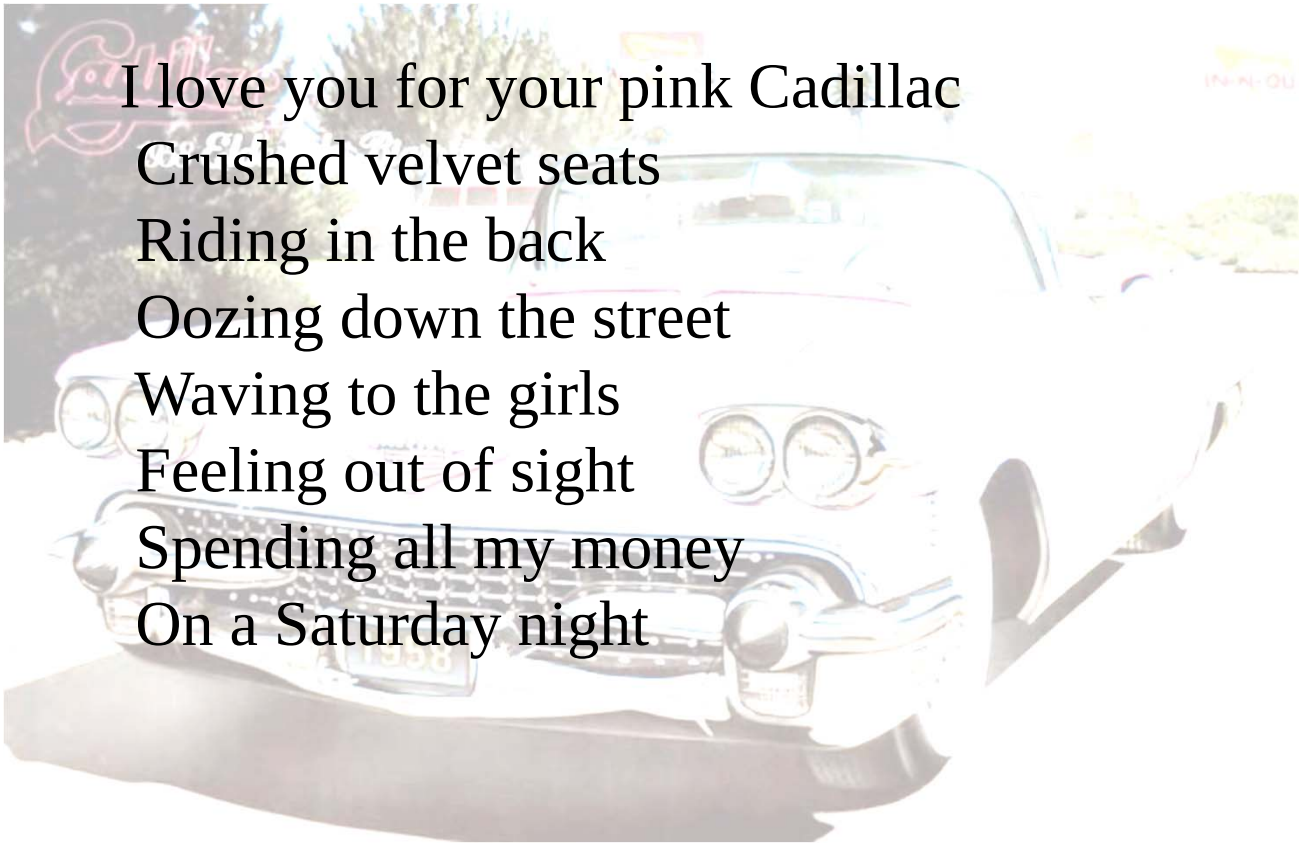
Davis & Caldeira PNAS 2010

Make Sustainability Fun

- New designs
- New business models
- Societal change to accommodate these changes

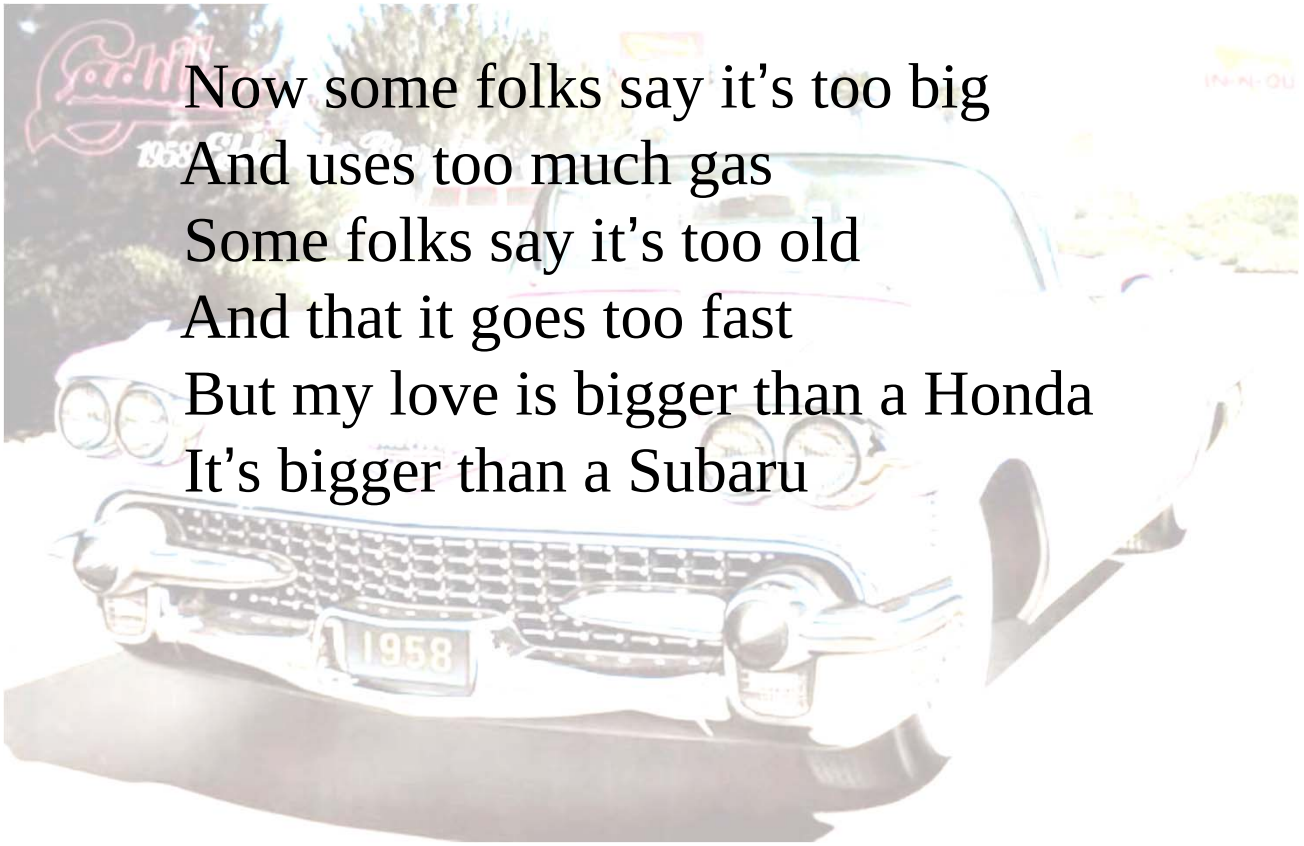
Pink Cadillac by Bruce Springsteen

The Desire



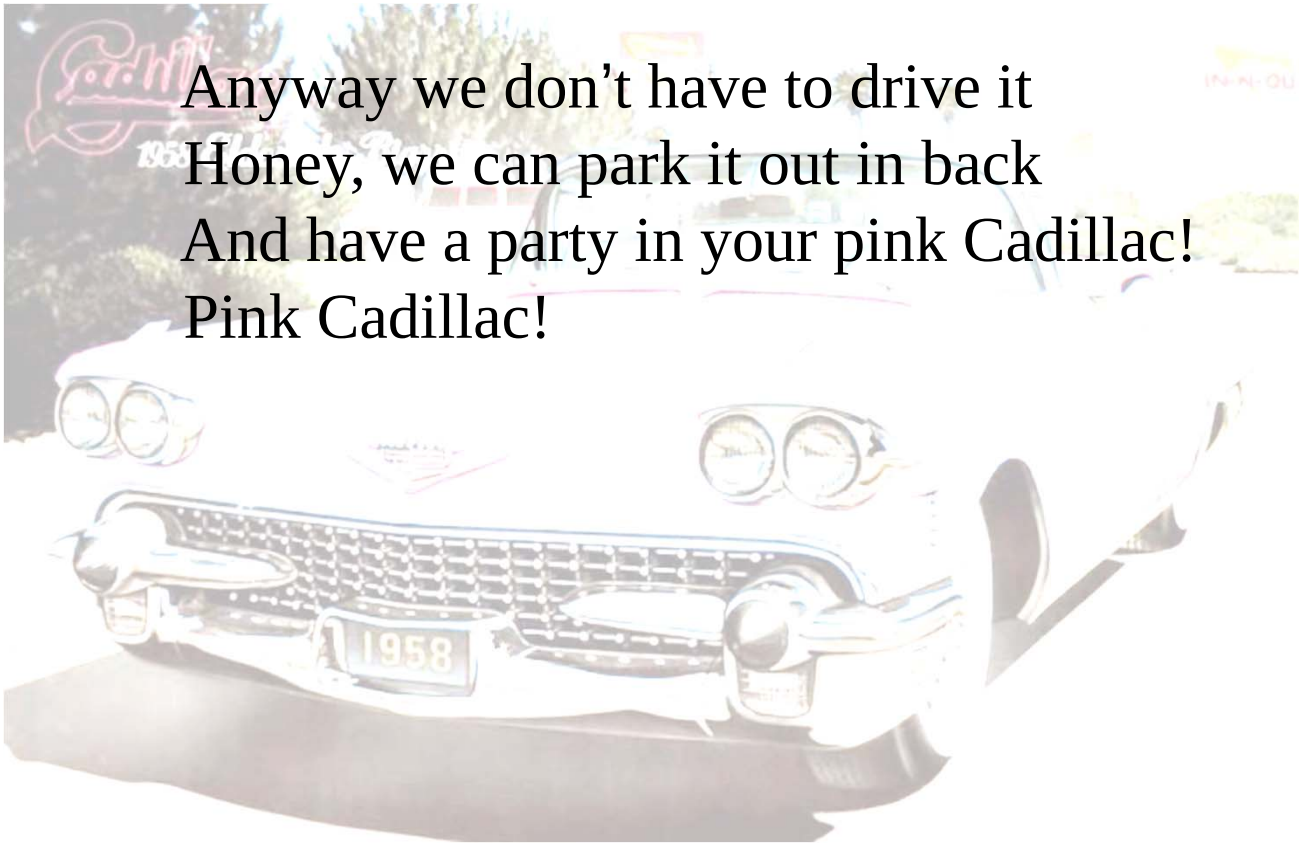
I love you for your pink Cadillac
Crushed velvet seats
Riding in the back
Oozing down the street
Waving to the girls
Feeling out of sight
Spending all my money
On a Saturday night

The Conflict



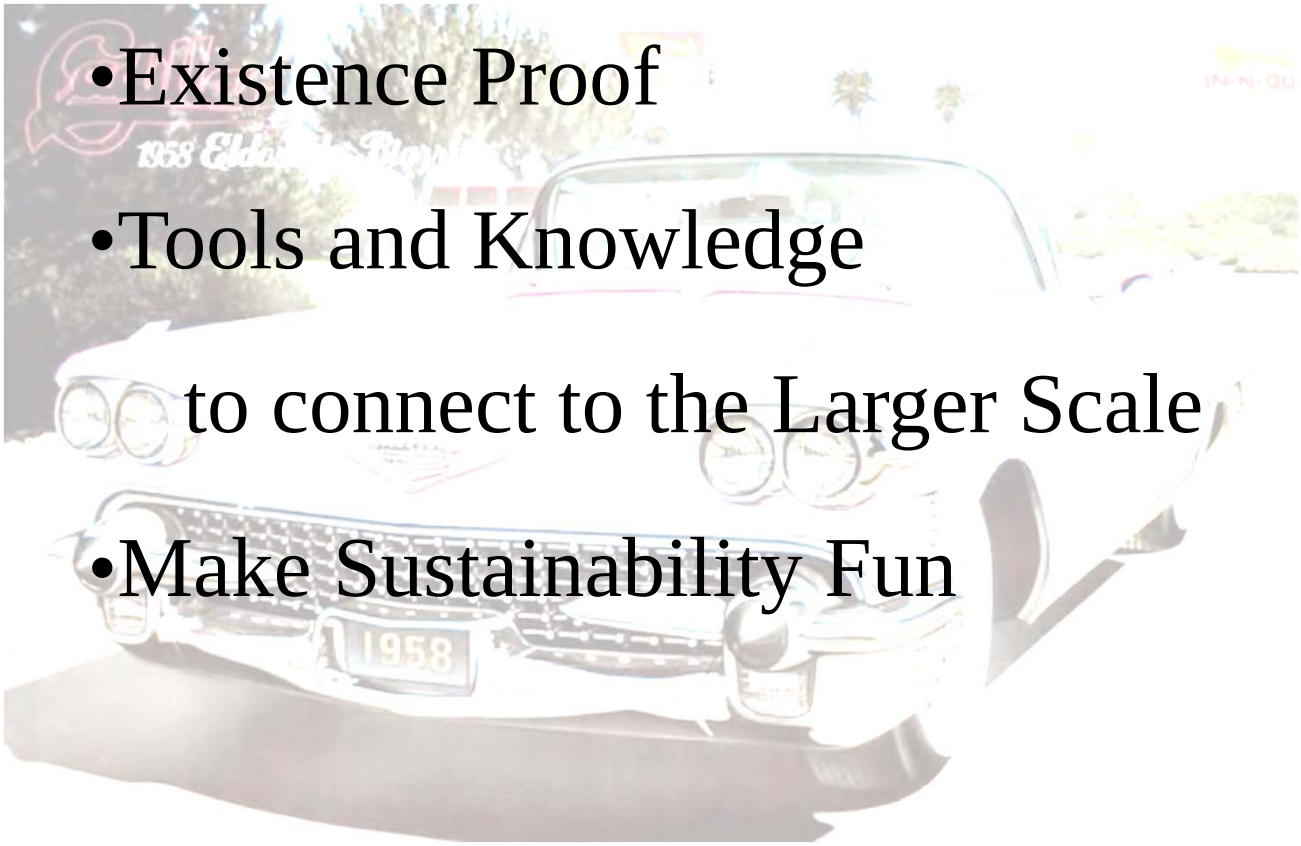
Now some folks say it's too big
And uses too much gas
Some folks say it's too old
And that it goes too fast
But my love is bigger than a Honda
It's bigger than a Subaru

The Resolution



Anyway we don't have to drive it
Honey, we can park it out in back
And have a party in your pink Cadillac!
Pink Cadillac!

What Engineers Can Do



- Existence Proof
- Tools and Knowledge

  to connect to the Larger Scale
- Make Sustainability Fun

Thank You