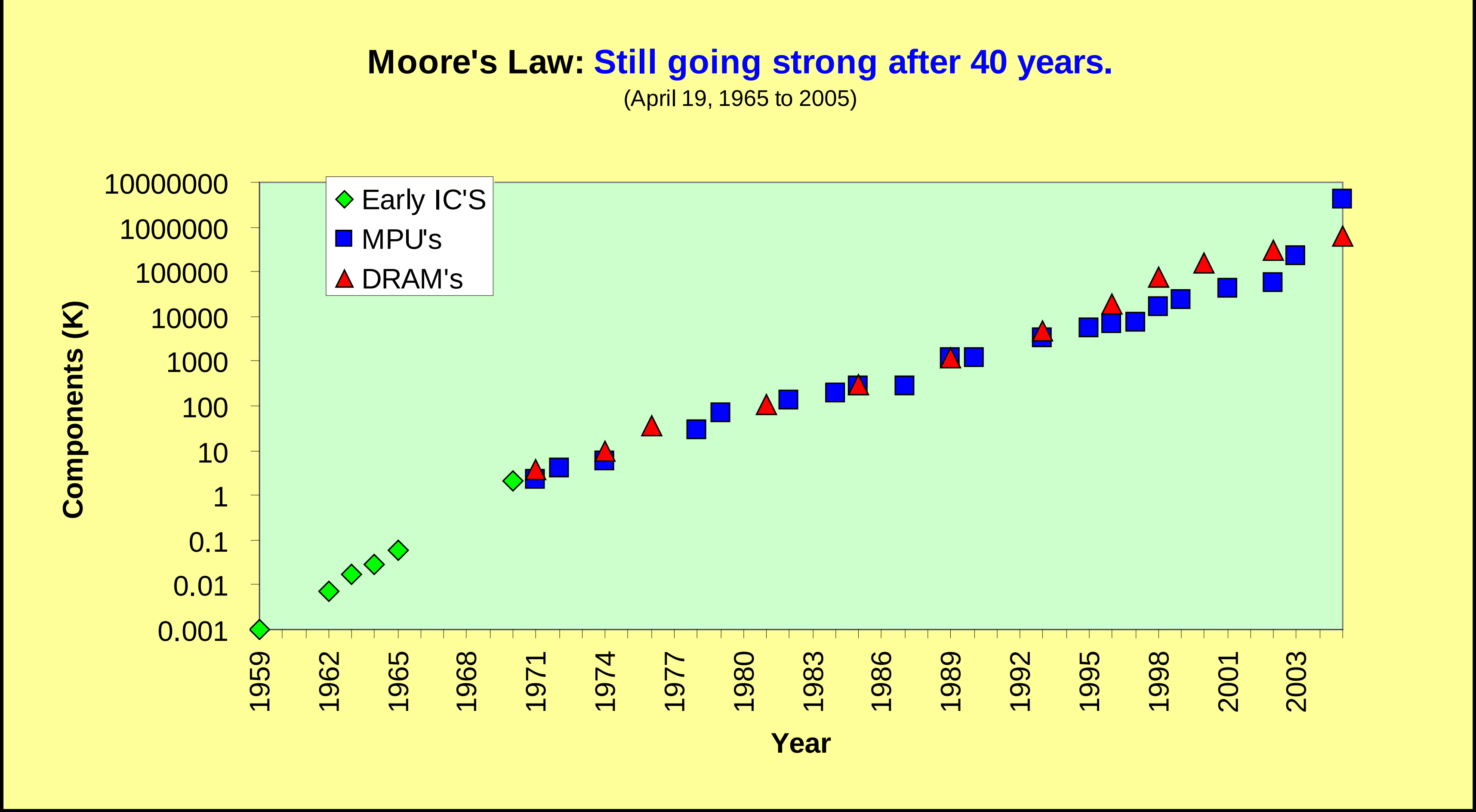
Moore's Law

and the race to the bottom

By G. Dan Hutcheson

Moore’s Law: The Definition

- *“The definition of “Moore’s Law” has come to refer to almost anything related to the semiconductor industry that when plotted on semi-log paper approximates a straight line.” – Gordon Moore*
- Moore’s Law postulates that the level of chip complexity doubles in a period of time.
- That cost of manufacturing a transistor decreases at a rate that is nearly inversely proportional to the increase in the number of components.
- Because, the cost of making any given integrated circuit at optimal transistor density levels is essentially constant in time.
- So the cost per component, or transistor, is cut roughly in half for each tick of Moore’s clock.



So far, nothing seems to get in the way – despite recurring dire predictions that started as early as 1968.

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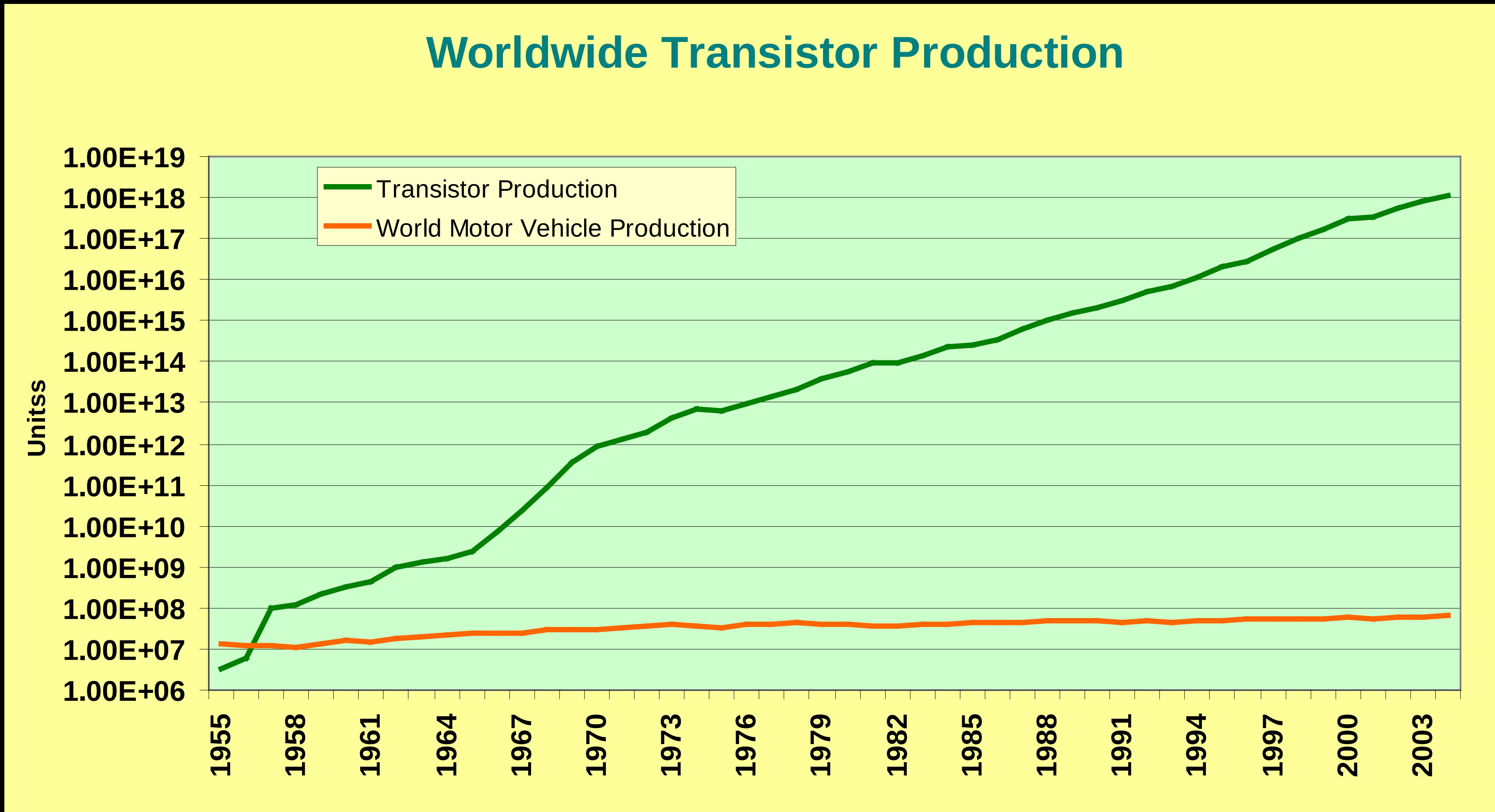
The Early History

- 1887– Karl Marx notes that for every question science answers, it creates two new ones; and the answers are generated at minimal cost in proportion to the productivity gains made.
- 1926 – Julius Lilienfeld conceptualizes solid-state amplifier.
  - Patent issued 1930.
- 1934 – Oskar Heil patents FET.
- 1947 – John Bardeen, Walter Brattain, and William Shockley invent the point-contact transistor.



It's an amazing picture of Man's ability to triumph over nature:

We have crossed 12 orders-of-magnitude milestones in 50 years.

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The IC unfolds

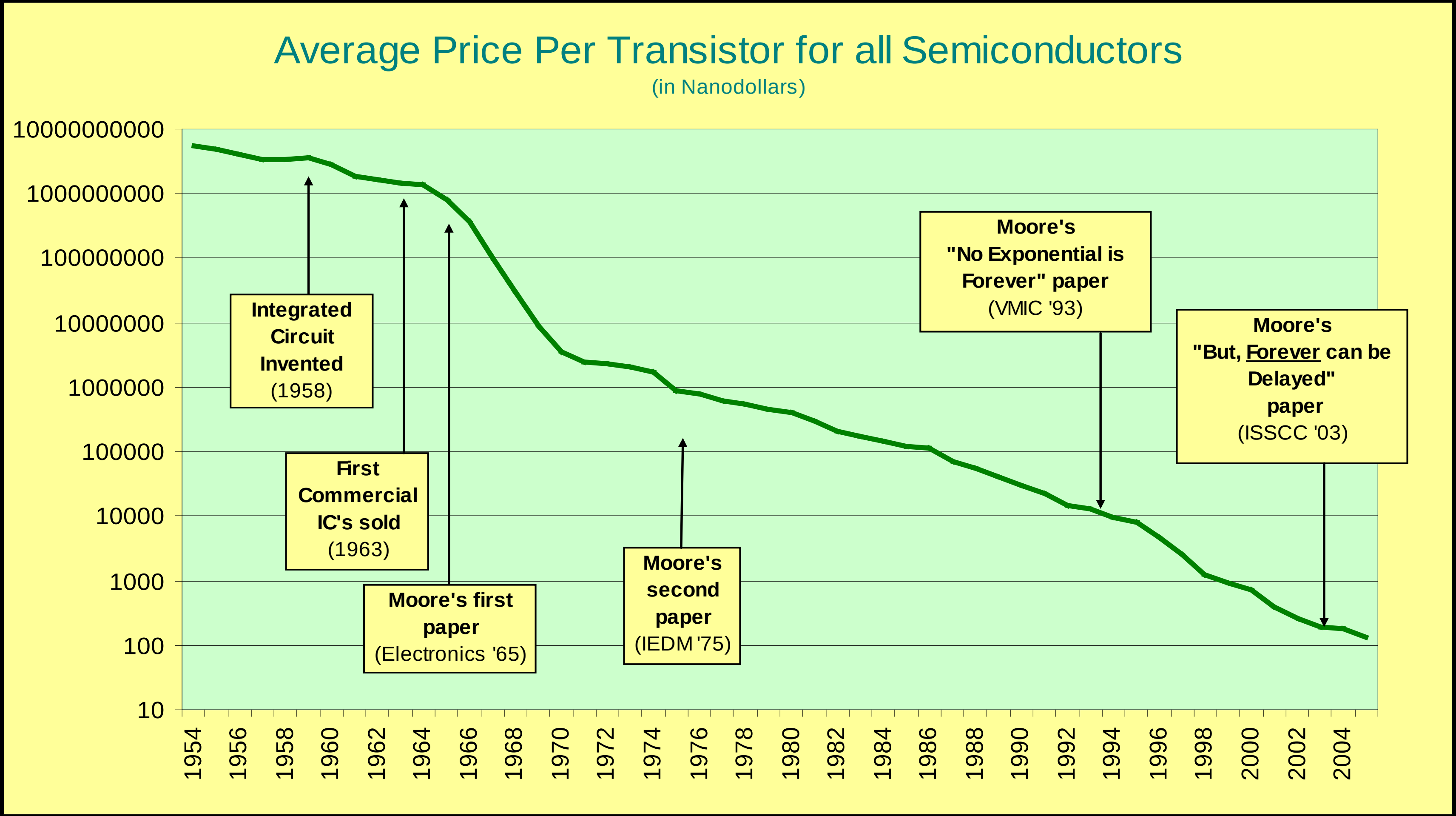
- 1957 – “Traitorous Eight” leaving Shockley Transistor in 1957 to start Fairchild Semiconductor.
- 1958 – Jean Hoerni invents the planar process
  - Only viewed as an important improvement in manufacturing.
- 1958 – Jack Kilby wire bonds components together to make first IC.
    - Done over Christmas Holiday and formally unveiled in March 1959
- 1959 – Robert Noyce has idea of using planar process to make IC. Modern IC invented.
    - Entered in engineering notebook, January 1959

The painful path to market

- 1960 – Moore tells senior marketing person, “Do not oversell the future of integrated circuits. ICs will never be as cheap as the same function implemented using discrete components.”
- 1963 – First commercial IC shipped by Fairchild.
- 1965 – Gordon Moore’s Paper published in Electronics on page 114.

Moore's Law kicks in

- 1968 – Intel founded with ML strategy.
- 1975 – Moore's 2nd paper:
  - Node clock slowed from 12 to 24 months.
  - Tax law plays a factor. 12 months too fast to depreciate.
- Intel's success came in large part due to a better understanding of Moore's Law.
  - They paced to system introductions.



If the semiconductor were fully adjusted for inflation, its size in 2004 would have been 6 million-trillion dollars . . . or 10's of K x GWP.

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Chip Making is

<u>the Engine</u>

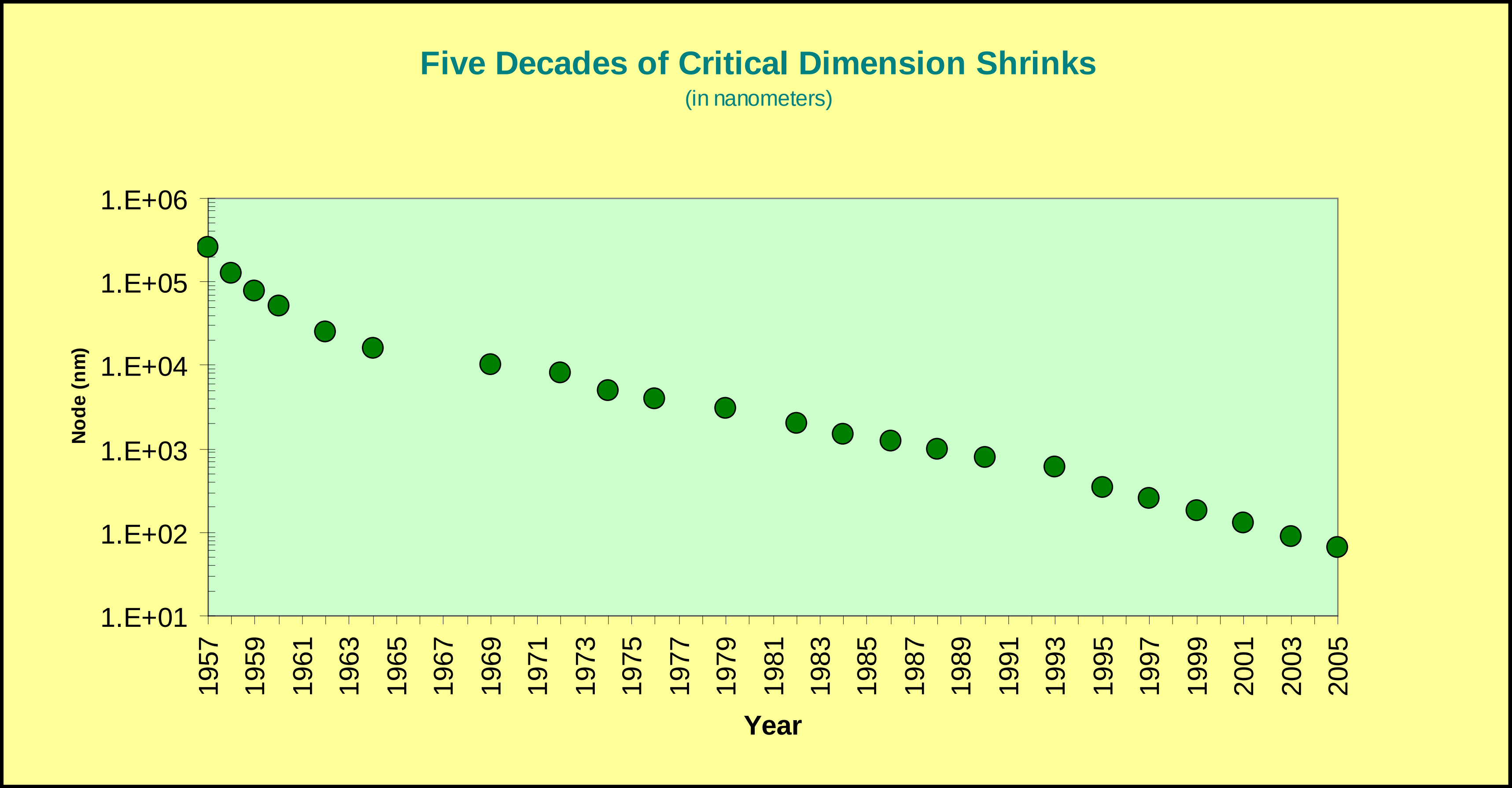
of the New Economy!

Why did Moore's paper prove so important?

- Moore recognized the business import of the manufacturing trends.
- He comprehended the future improvements in manufacturing that would drive linewidths ever smaller.
- He provided the business model for how this would drive costs.
- He distilled it into a vision that the industry grabbed hold of – making it a self-fulfilling prophecy.

This story was made possible by manufacturing's ability to shrink transistors:

We have crossed 4 orders-of-magnitude milestones in 48 years.



Moore's Law: How we got here

Year	CD (nm)	Lithography Technology
1957	254,000	Camel's Hair Brush
1958	127,000	Silk Screen Printer
1959	76,200	Contact Printer – Emulsion plates
1964	16,000	Contact Printer – Chrome plates
1972	8000	Proximity Aligner
1974	5000	Projection Aligner
1982	2000	g-line Stepper
1990	800	i-line Stepper
1997	250	248nm Scanner
2003	90	193nm Scanner

- *We've gone from 10 cents to 25 Million Dollars and Moore's Law is still alive.*

But no Exponential Lasts Forever

- Bigger more powerful trains.
  - Union Pacific DDA40X
- Bigger Jets.
  - Boeing 747
- Faster Jets.
  - Concorde supersonic transport.
- Faster Cars.
  - Freeways designed for safe speeds above 100 MPH.
  - Ferrari Enzo capable of more than 200 MPH.

Technology Drives

Economics Limit

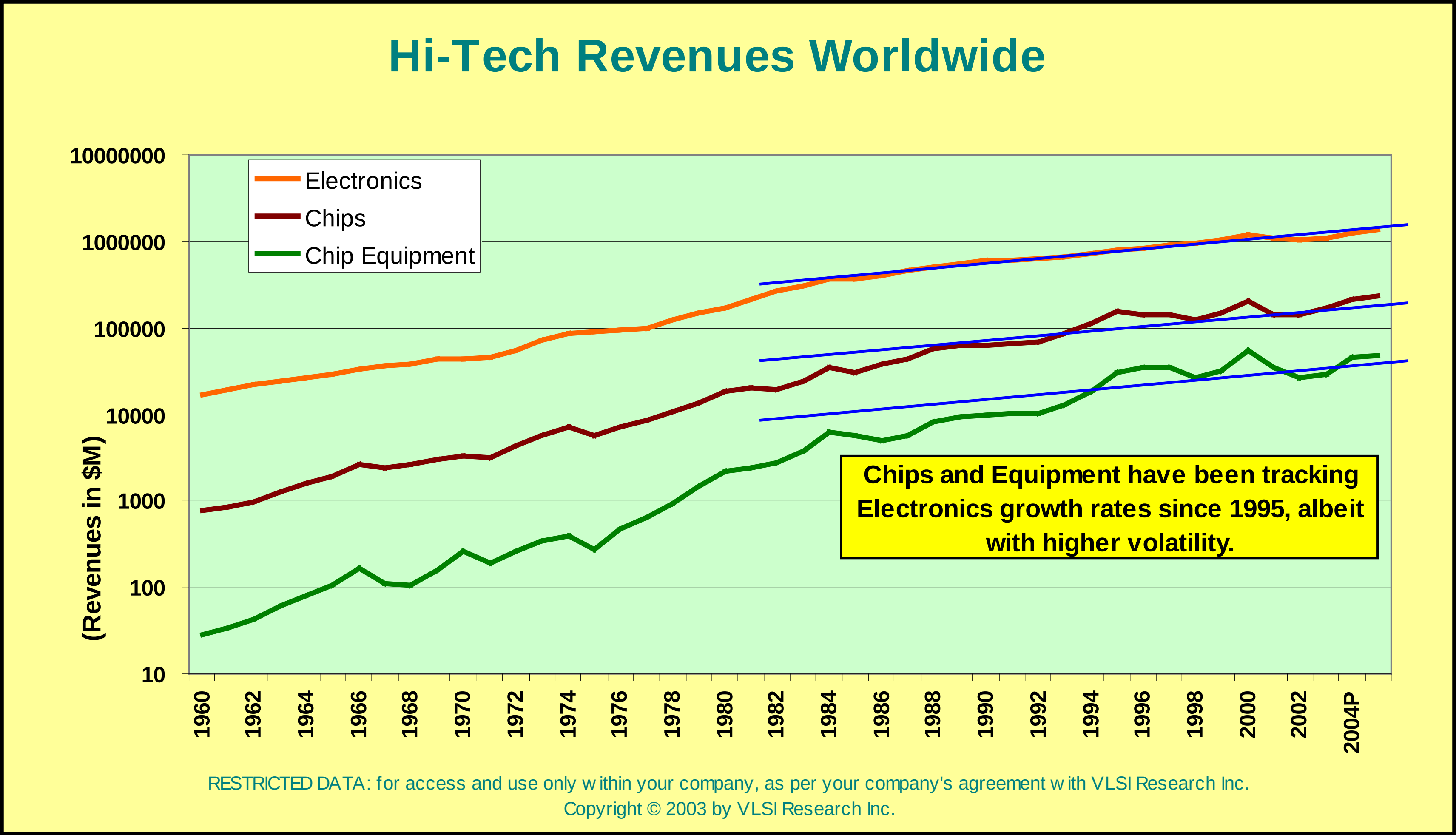
Will something similar happen to chips?

- Customers don’t need more integration?
- Can’t shrink anymore?
- CMOS doesn’t work anymore?
- Fabs too expensive?

- But we have proven amazingly able to beat the experts – *It is the engineering feat of modern times.*

Customer’s don’t need more integration

- There is no abatement in the demand for transistors.
- There is an innate human need to store and process information.
  - 30000 BC: Chauvet cave drawings
  - 9000 BC: Sumerian clay tokens
  - 3000 BC: Tokens replaced with tablets
  - 2000 BC: Egyptians develop Papyrus paper
  - 105 AD: Ts’ai Lun invents wood based paper
  - 1436 AD: Johann Gutenberg invents printing press
  - 1456 AD: Gutenberg bible published
  - 1876 AD: Melville Dewey publishes classification system
  - 1936 AD: Alan Turing decribes the “Turing Machine”



But industry growth has slowed. First in 1985 and again 1995.

For more: see my ISSM 2003 Keynote at chiphistory.org

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Moore’s Wall:
We can’t shrink anymore

- Even Gordon had faith in optical

“It is worth noting that this density of components can be achieved by present optical techniques and does not require the more exotic *electron beam* operations which are being studied for the possibility of making even smaller structures . . .
for “Transistors on 2 mil centers.”

– Gordon Moore, Electronics, 1965

- *Despite repeated predictions of its demise, optical lithography is still here.*

What does Gordon have to say about when Moore’s wall will appear?

“Who knows? I used to argue that we would never get the gate oxide thickness below 1000 angstroms and then later 100. Now we’re below 10 and we’ve demonstrated 30nm gate lengths. We can build them in the 1000’s. But the real difficulty will be in figuring out how to uniformly build tens of millions of these transistors and wire them together in one chip.”

– Gordon Moore in The Chip Insider, May 25, 2001

No one can predict it, but we have always found a way around it.

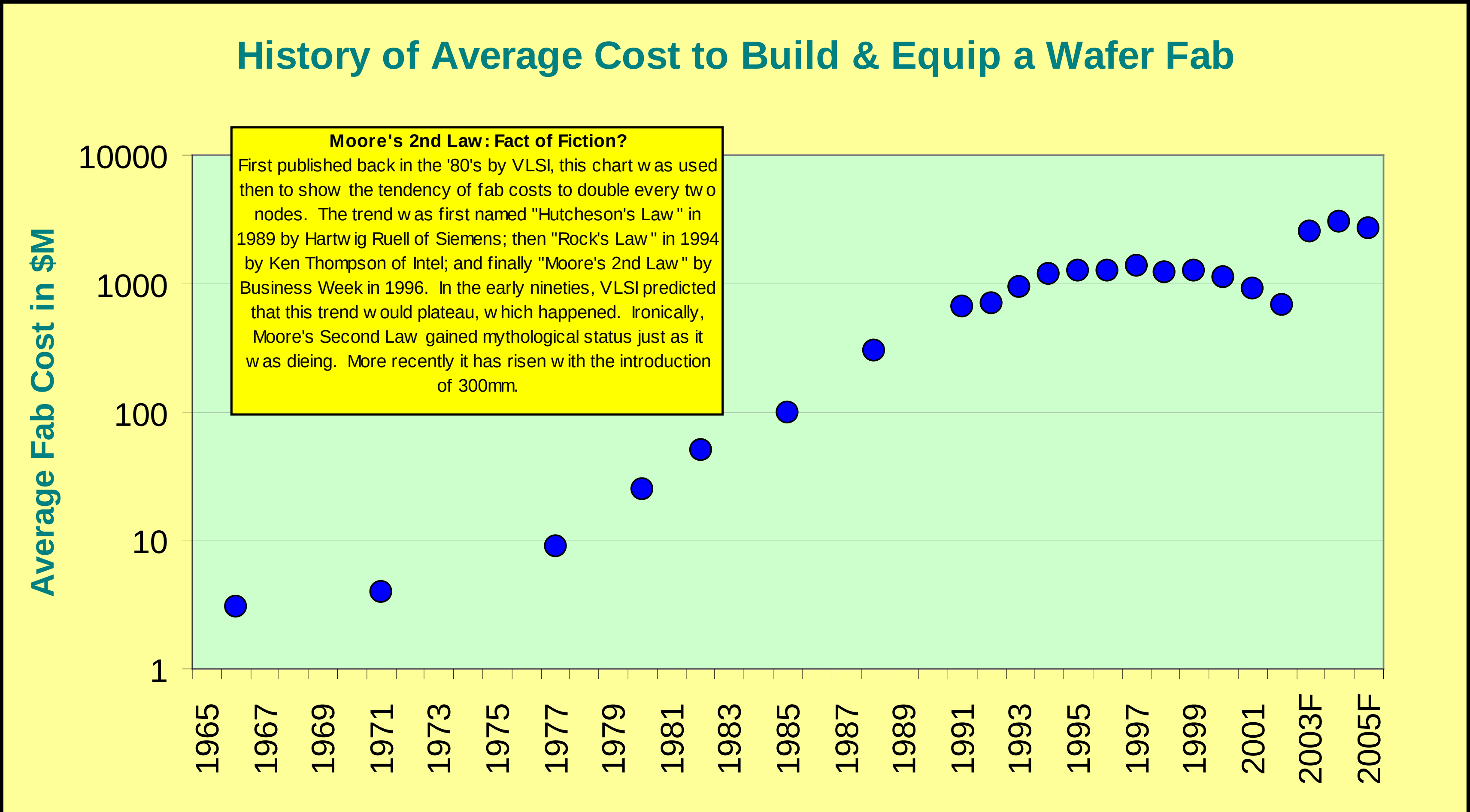
CMOS doesn't work anymore

- CMOS wasn't the beginning
  - Point Contact, Mesa, NPN, PNP, DMOS, PMOS, NMOS preceded it.
- CMOS won't be the end
  - Spintronics, carbon nanotubes, nanowire
- There's still plenty of room left at the bottom.
- But, lithography may have to get replaced with self-assembly.

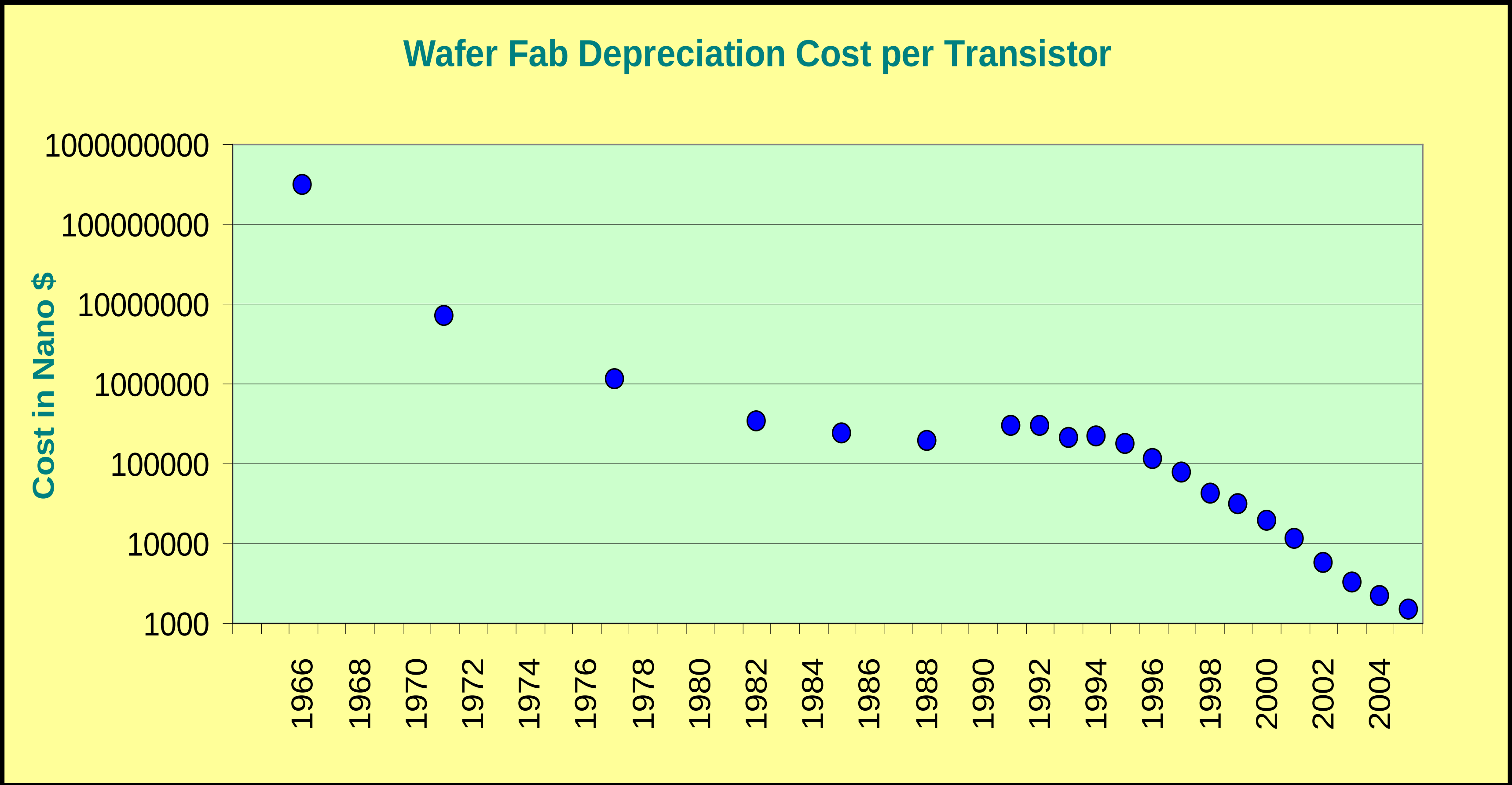
Fabs too expensive

- It is generally accepted that cost-per-function needs to decline by 30% per node.

- That allows the manufacturing cost per unit area of silicon to rise by 40% per node.
  - It's simple math.



Fab costs came down with the dotcom crash. The shift to 40K WSM fabs doubled costs. Otherwise, 300mm costs little more than 200mm.



Depreciation per transistor is what drives Moore's Law:
It continues to go down, proving that fabs are not too expensive.

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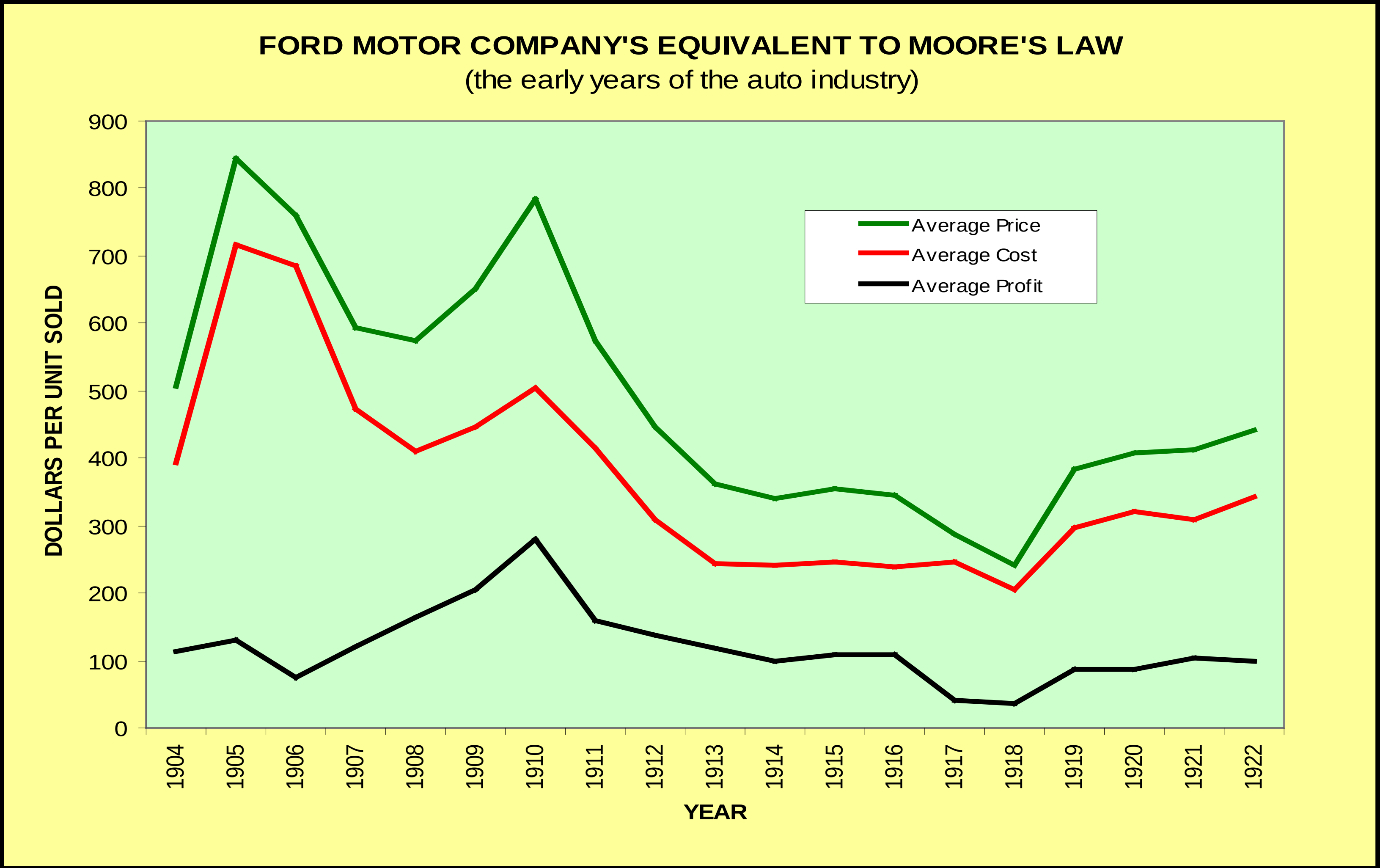
Moore’s Wall: Does the show really stop?

– It didn’t for Autos.



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Moore's Law

- It's still alive and well, with no signs of abating.
- Saturation is slowing the industry's growth.
- Fab costs are not a threat.
- Even if Moore's Wall does appear . . .

THE SHOW MUST AND WILL GO ON!

or . . .

a sunset doesn't mean there won't be a new day.

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