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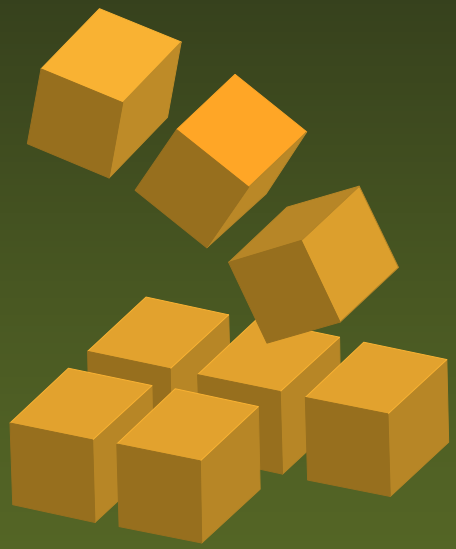

Photonics becomes greener over the next decade

Michael S. Lebby

GM & CTO

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3 key takeaways…

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- Photonics enables many things and is part of our lifestyle
- Photonics will be designed for many products and applications
- Photonics is green and will enable new technologies and products ***that will also be green…***

Lifestyle, photonics, green

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Green photonics…

Long term impact

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USA's biggest (passive) weapon

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- Saving energy → less oil → less dependence on fossil fuels

It's a lifestyle…turn things off…

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Photonics in renewables…

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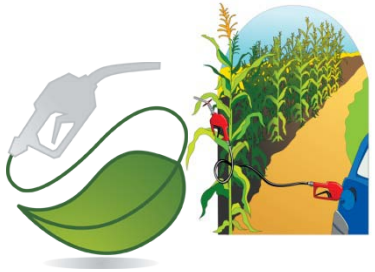
- **Barrier:** Scaling up renewable GW in our infrastructure
  - Cost of renewable electricity
  - Performance and reliability
  - Infrastructure robustness and capacity
  - Simplfying dispatchable energy (wind)



- **Barrier:** Obsoleting petroleum (fossil) based fuels
  - Cellulosic ethanol cost (wood, grass, non-edible plants)
  - Life cycle sustainability of biofuels
  - Fuels infrastructure, standards, metrics
  - Demand, utilization and intermediate blends

- **Barrier:** Shrinking energy demand of buildings, automotives, etc
  - Coordinated implementation of model building codes
  - Market does not value efficiency
  - Cost of energy efficient technologies
  - Performance and reliability of new technologies


Sources: NREL, Dan Arvizu

Decade programs: attitude → cultural

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Will the oil era come to an end?

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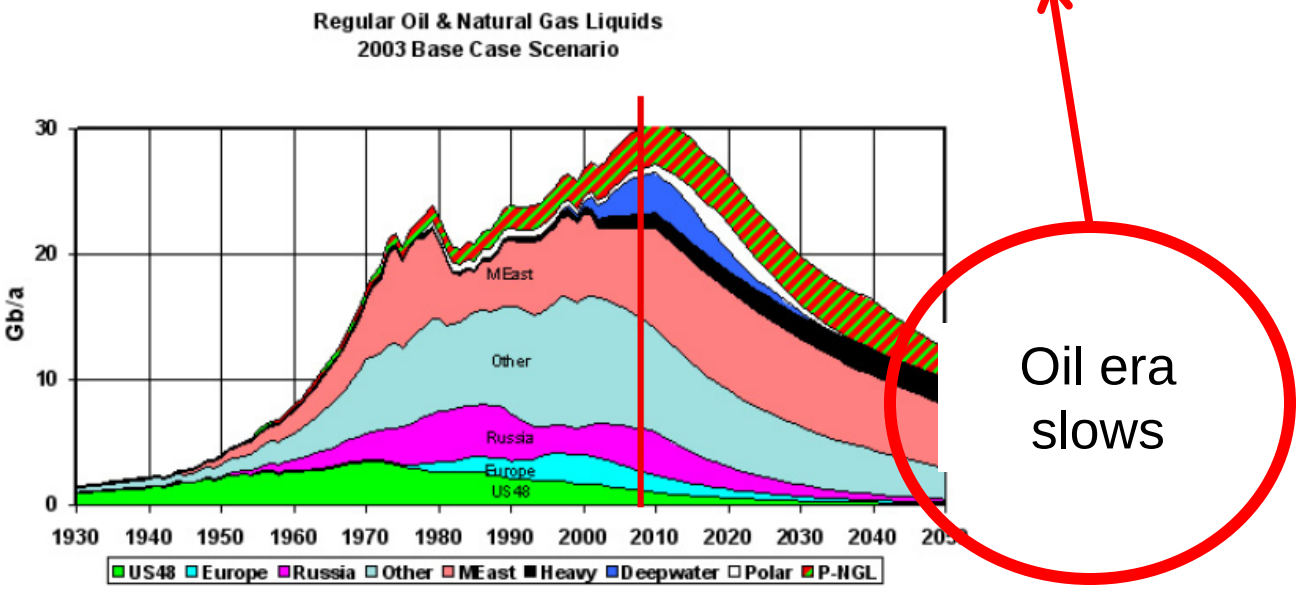
The Need for Renewable Energies

The start of a new era of creative, innovative technologies



Source: Christoph Harder Swiss Laser Network, Oerlikon Solar, Uppsala hydrocarbon depletion study group

Stage entry for new technology…

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Whole planet?

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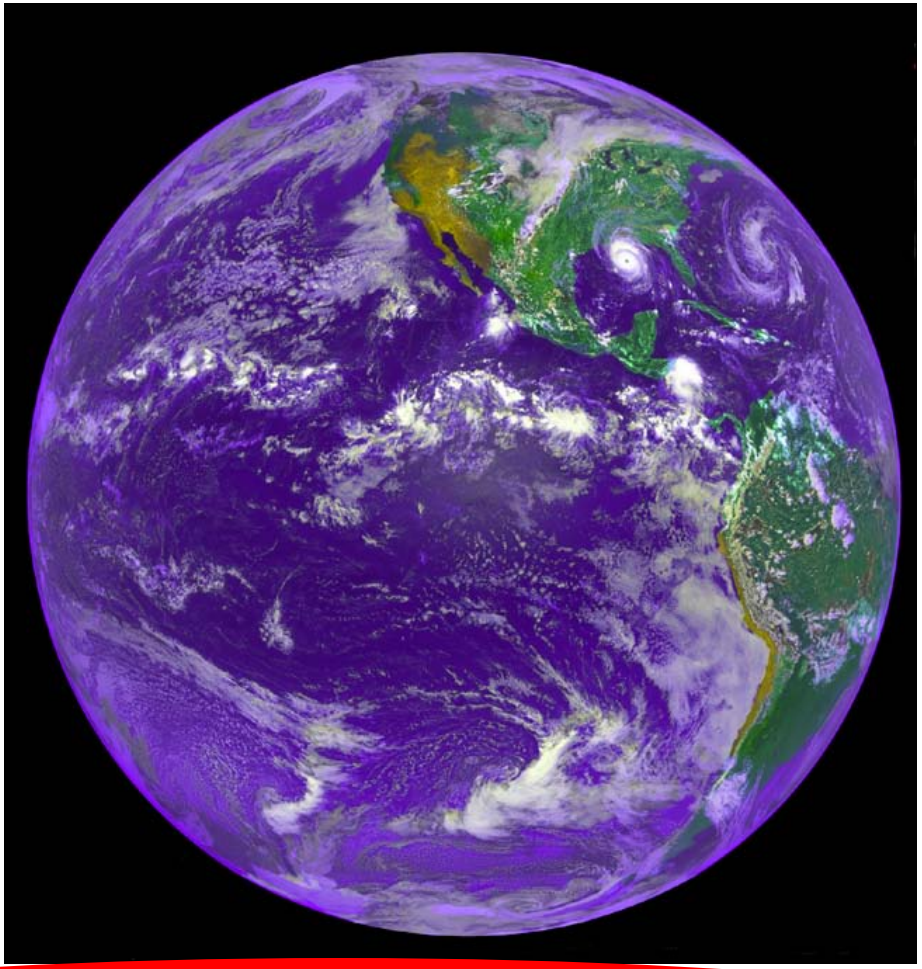
- 50yrs,
- 100yrs,
- If ever?



Sources: Kurtz NREL

Important issue in public minds…

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The green value chain…

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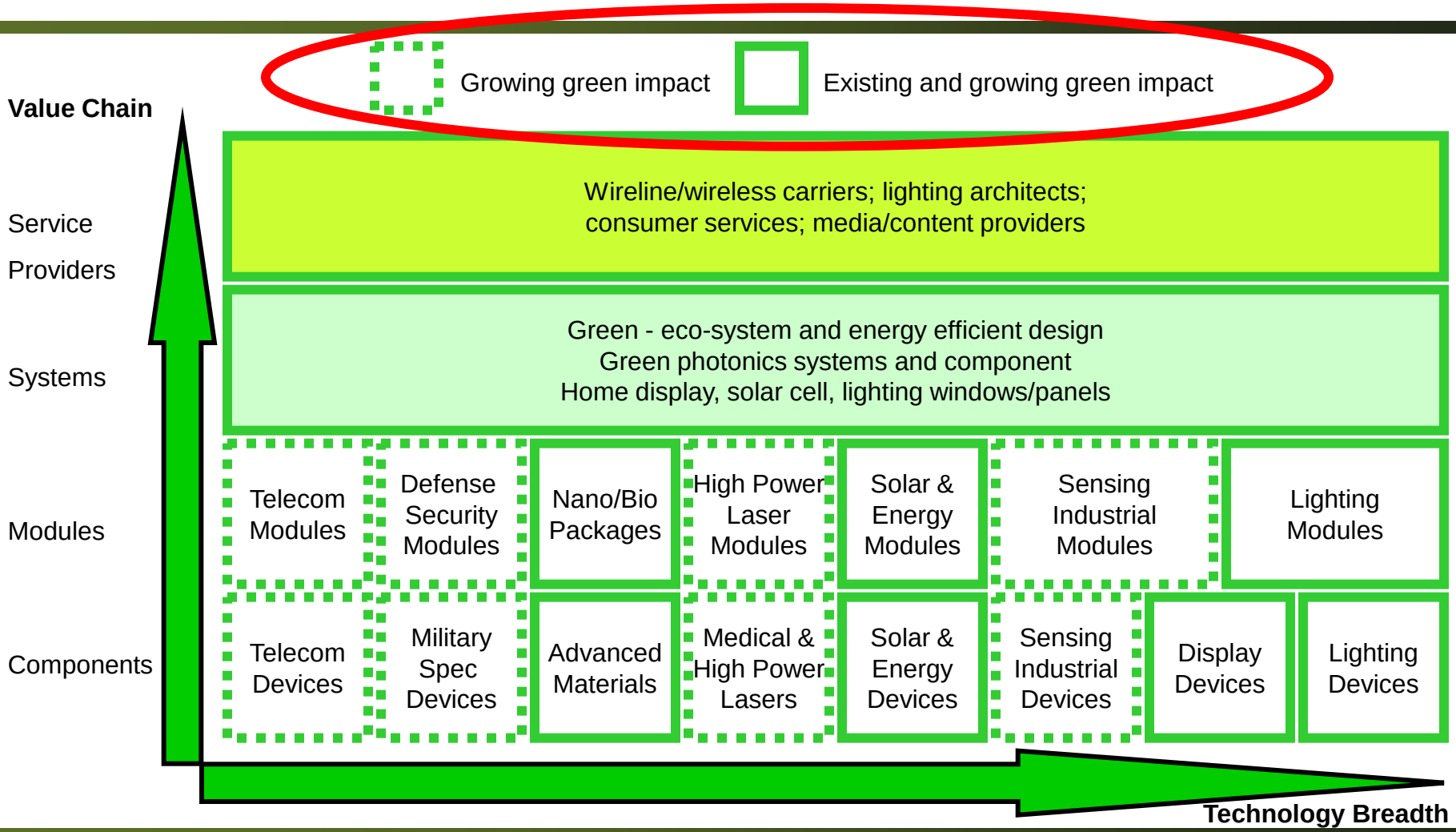

Sources: OIDA research, Translucent Inc

Green has a huge impact in society…

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In a decade…

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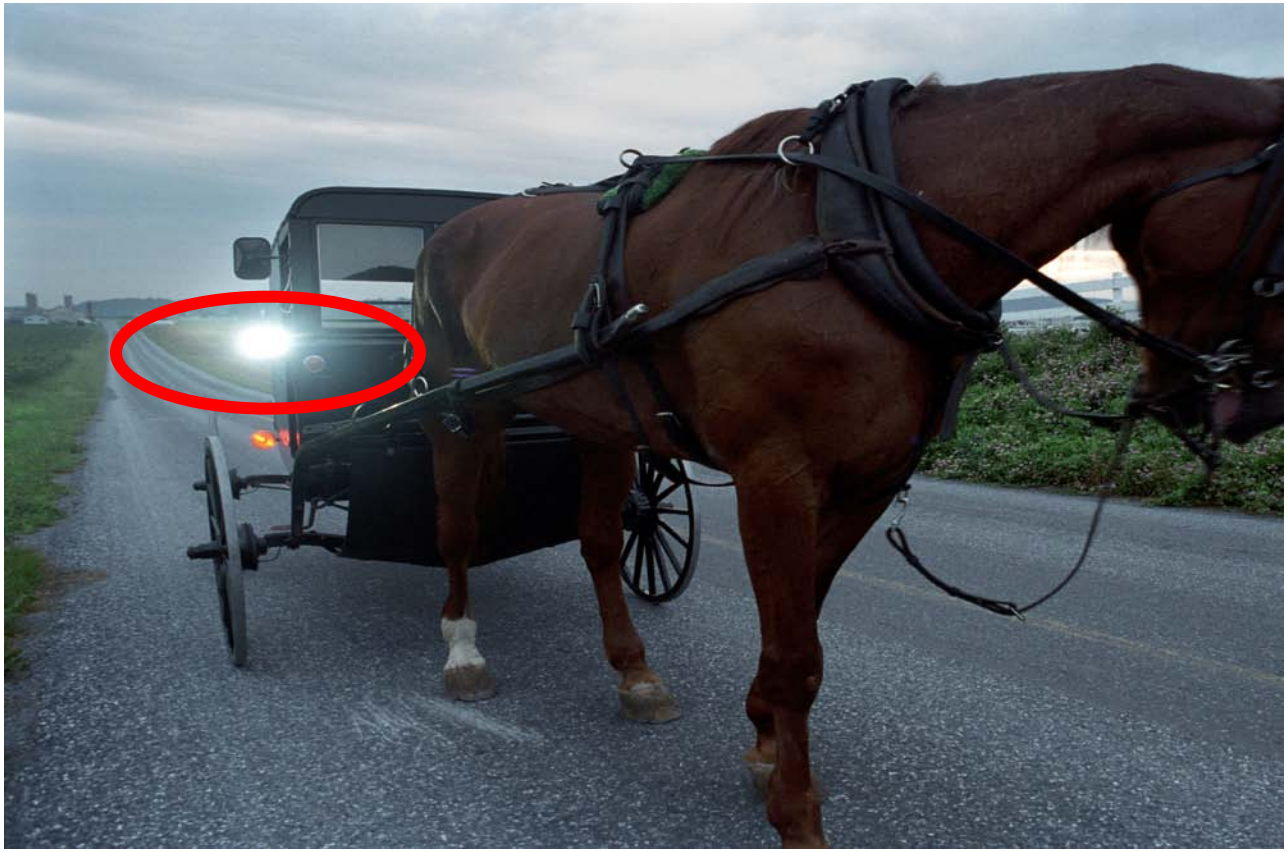
- A truly green vehicle with LEDs and solar panels…



Sources: Philips Lumileds, OIDA, George Craford

Extreme but effective…

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Photonics markets...are already global

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Asia dominant in OE/photonics

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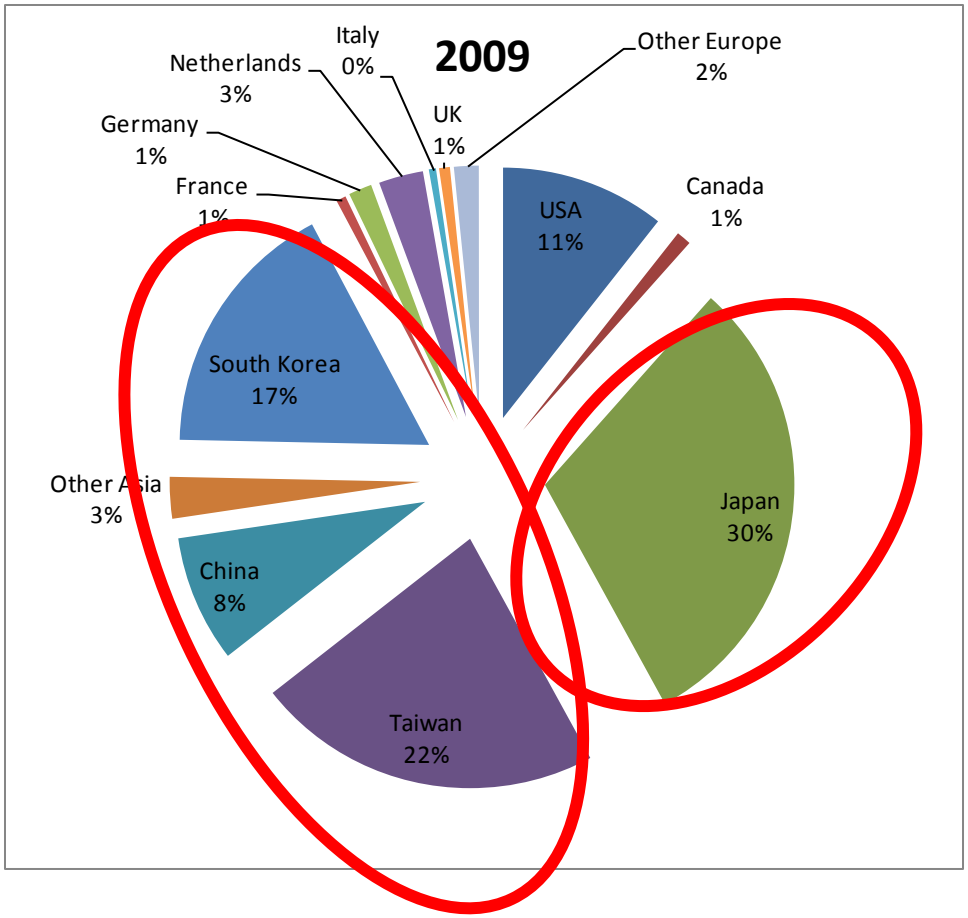
- Asia owned 81% of global 2009 OE market of $353B



Sources: OIDA research, IOA

North America & Europe minor players

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Market share in 2021

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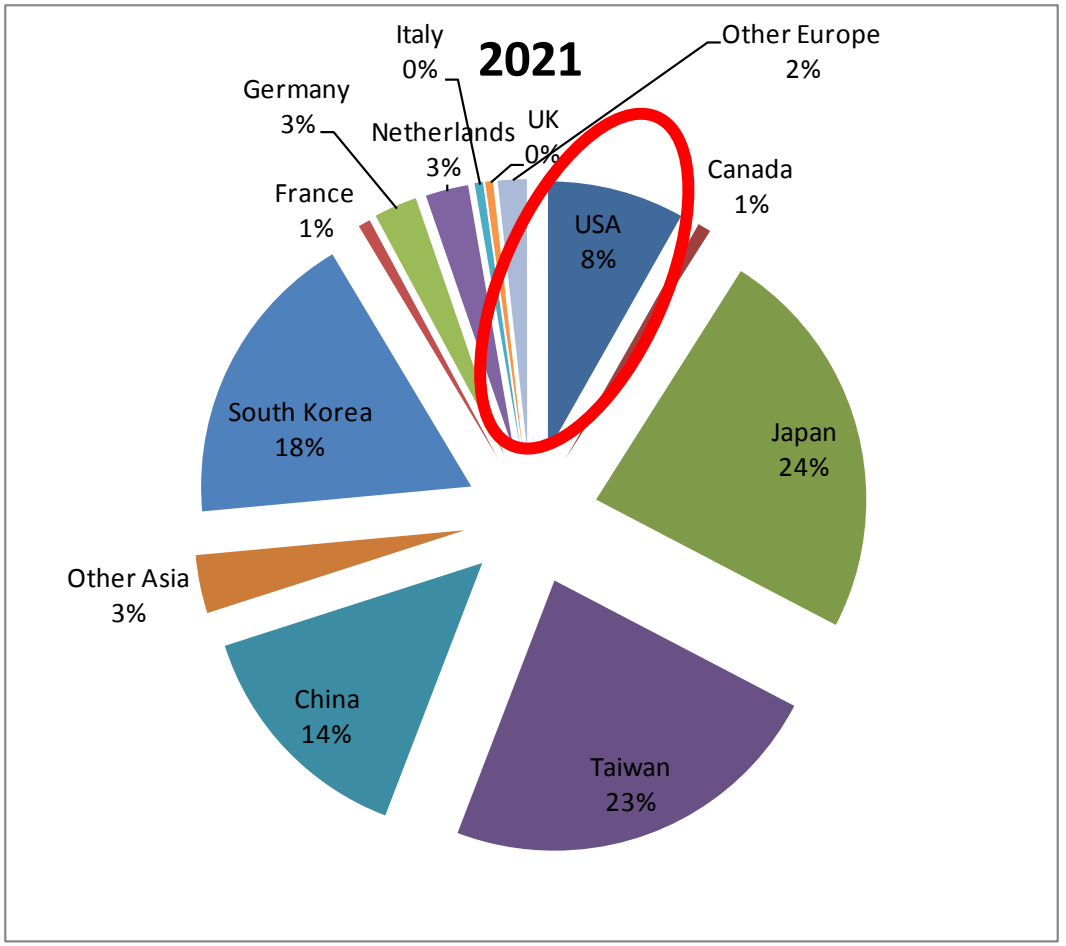
- USA
  - Down 11% → 8%



Sources: OIDA research, IOA

Asia remains strong

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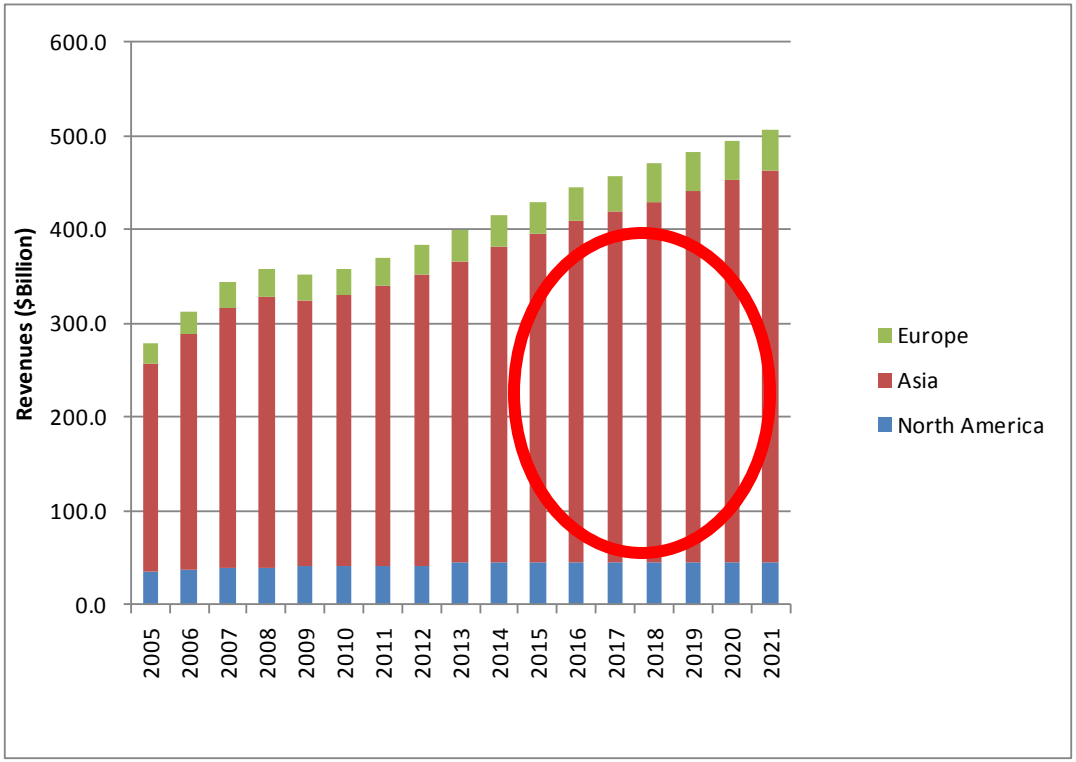
OE/photonics market by major location

Translucent Inc
Earth Abundant Materials Technology.

- By 2021, share: Europe 8.6%, USA 9%, and Asia 82.4%
- Asia photonics maintains growth (3.4% CAGR 2010-2021)



Sources: OIDA research, IOA

Asian infrastructure strongest

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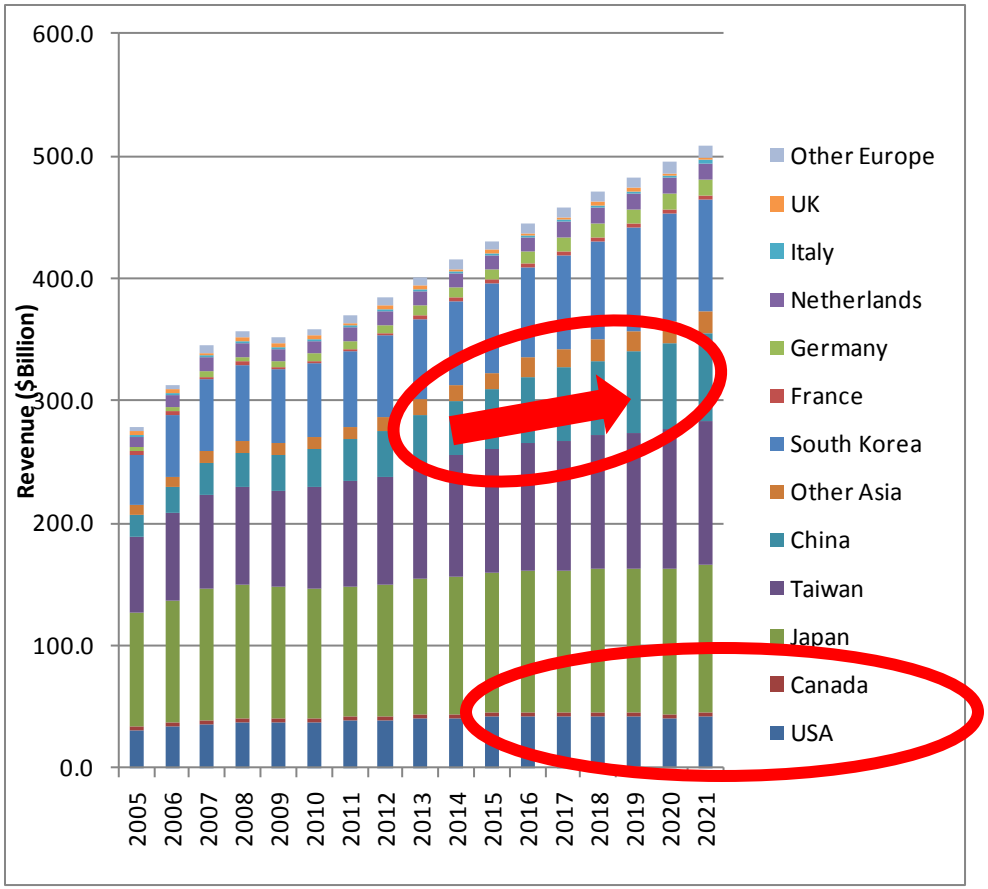
OE/photonics market by country

Translucent Inc
Earth Abundant Materials Technology.

- By 2021, OE/photonics will be a $500B business with many countries contributing…
- China grows quickly
- US constant



Sources: OIDA research, IOA

Design + manf → off-shore

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USA decade trends remain flat

Translucent Inc
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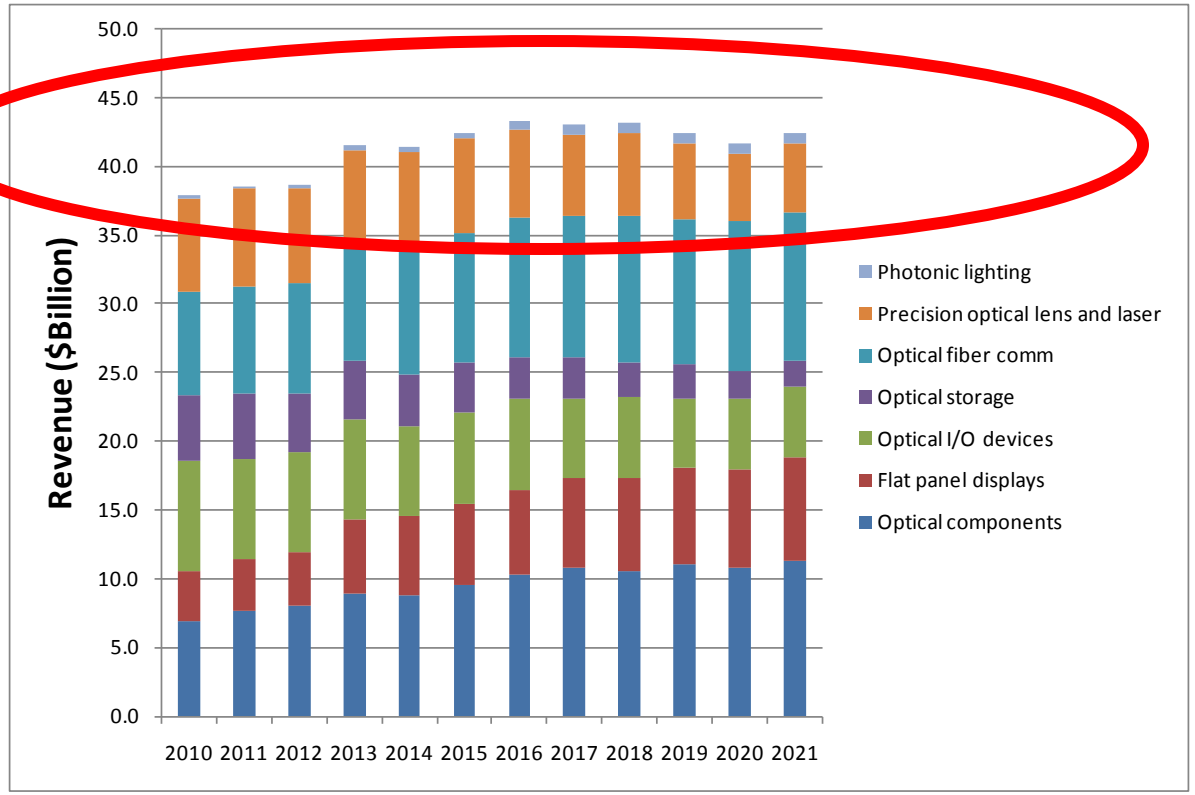
- Optical fiber communications and components strong
- Photonic lighting CAGR 2010-21 of 12.2%



Sources: OIDA research, IOA

USA → exporting photonics jobs?

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Green photonics will grow...

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Global OE/photonics market

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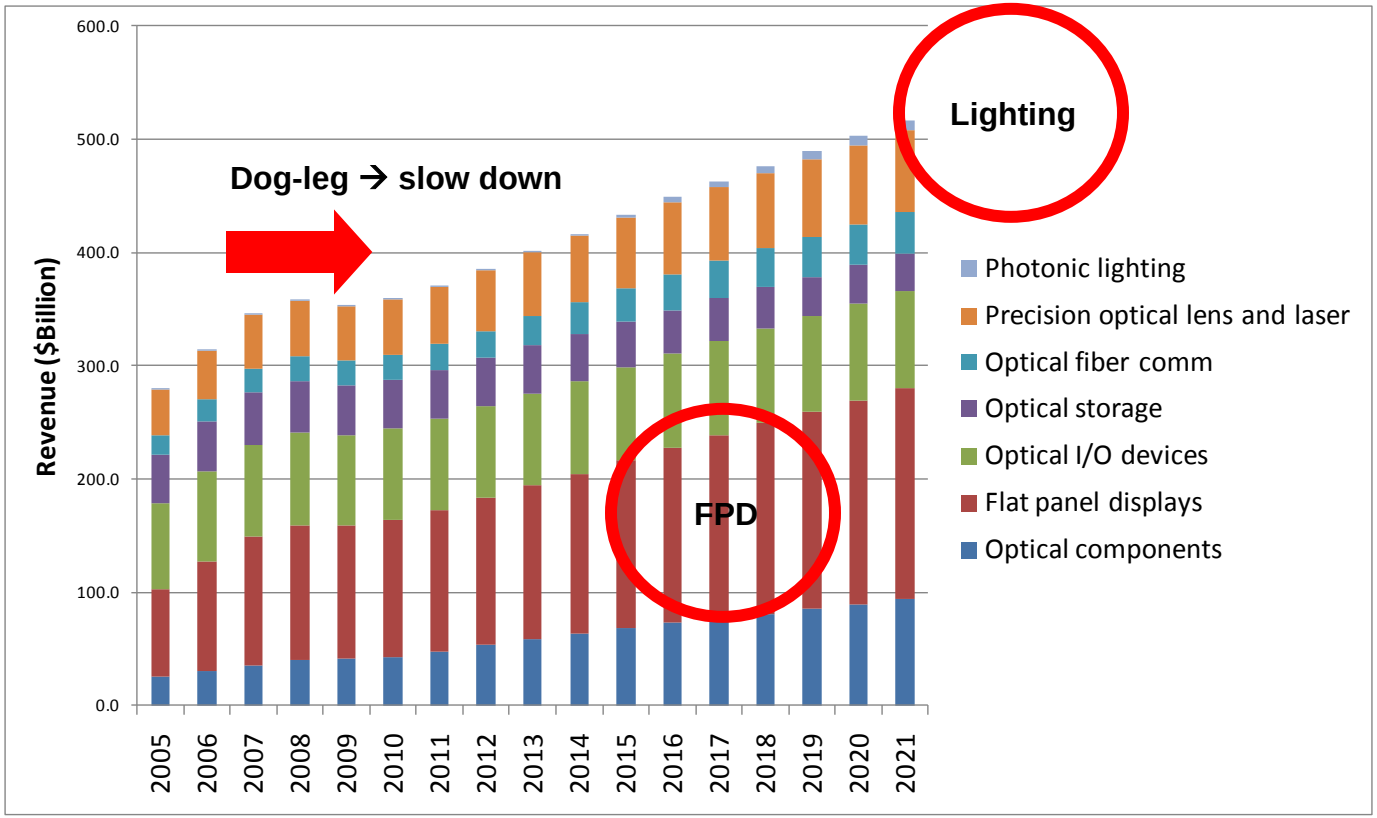
- Growing from $353B in 2009 to $516B in 2021
  - FPD big driver → 3.9% CAGR; SSL still best growth at 29% CAGR



Sources: OIDA research, IOA

Outlook is strong for photonics…

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Defining ‘green photonics’…

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- Contribution of photonics is considered “green” if it
  - Generates or conserves energy
  - Reduces greenhouse gas emissions
  - Reduces pollution
  - Yields a more environmentally sustainable outcome
  - Improves human health
- Methodology
  - Start with base optoelectronics market forecast
  - Analyze OE segments for green criteria
  - Aggregate all green segments for market total
  - Identify green elements of segments
  - Forecast the penetration rate to 2021
  - Expect criteria for green → stringent
    - Slowing penetration rates

Optoelectronic components
- HBLED
- Std led
- LED Module
- Linear CCD
- Area CCD
- Contact image sensor
- CMOS image sensor
- Solar cell

Flat panel displays
- LCD (tft)
- LCD (tn, stn)
- PDP
- VFD
- OLED
- Microdisplay
- LTPS TFT

Optical I/O devices
- DSC
- Copier
- Fax machine
- Multi-functional product
- Laser printer
- Bar code reader
- Scanner

Optical storage
- Consumer disc player
- Optical disc player for PC
- Re-writable disc
- Optical disc titles

Optical fiber comms
- Optical cable
- Optical passive components
- Optical communication equipment
- Optical active components
- Optical modules

Precision optical lens and laser
- Lasers
- Precision optical lens
- Laser application equipments
- Optical lens

Solid state lighting
- In-Organic LED
- Organic LED

Sources: OIDA research, IOA

Systematically reviewing OE segments…

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Global OE components mkt

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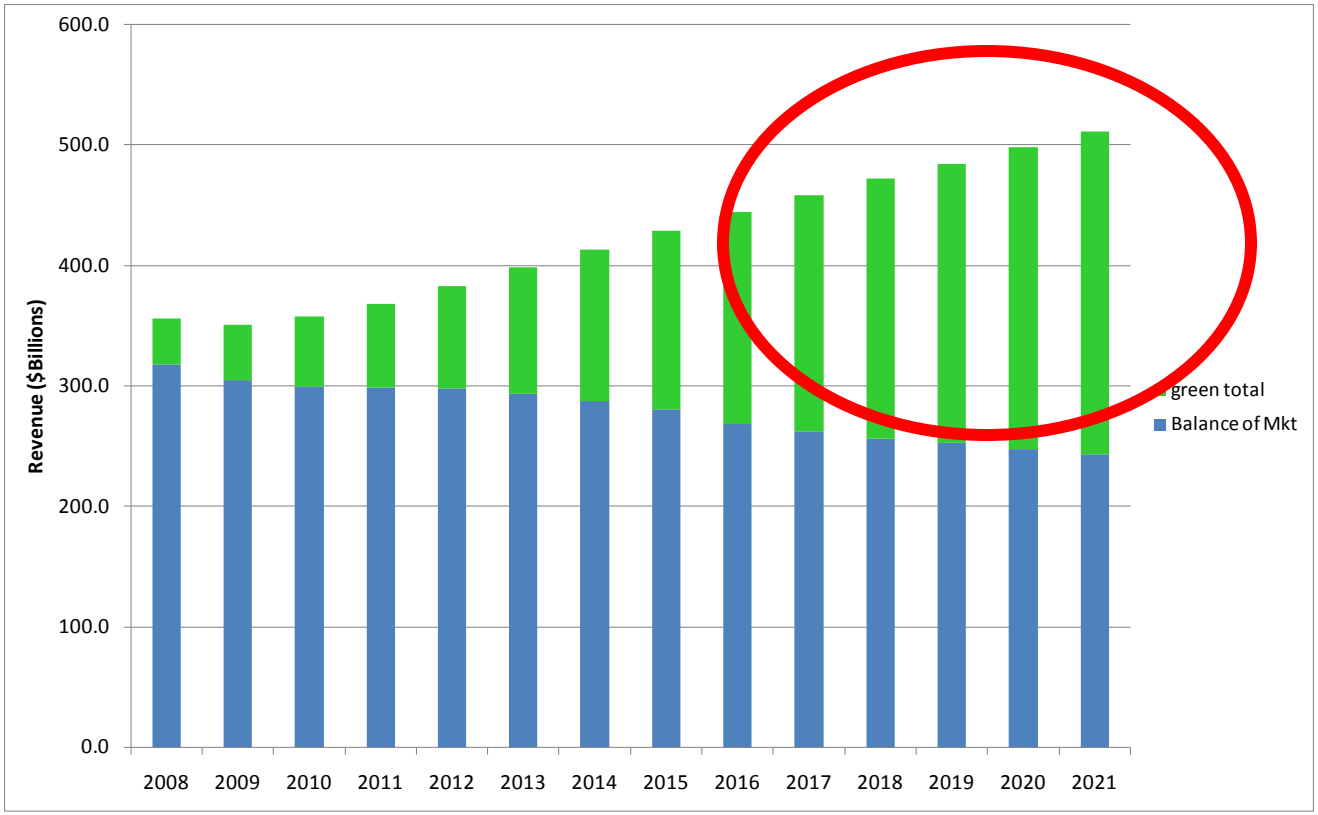
- Green portion grows quickly over decade
  - 13.3% ($46.6B) in 2008 to 52% ($243B) in 2021



Sources: OIDA research, Phil Wright WRT Associates

General acceptance of energy efficiency…

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Green OE by segment

Translucent Inc
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- FPD largest growing to $110B by 2021
  - OE components 2nd, reflecting large role of PV and HBLEDs

Sources: OIDA research, Phil Wright WRT Associates

Consumer applications big driver for green

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Networks must address scaling...

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Network as a catalyst for change in lifestyle

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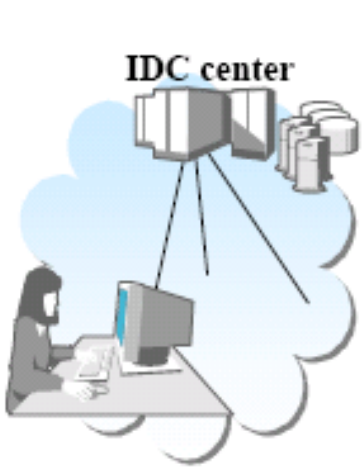
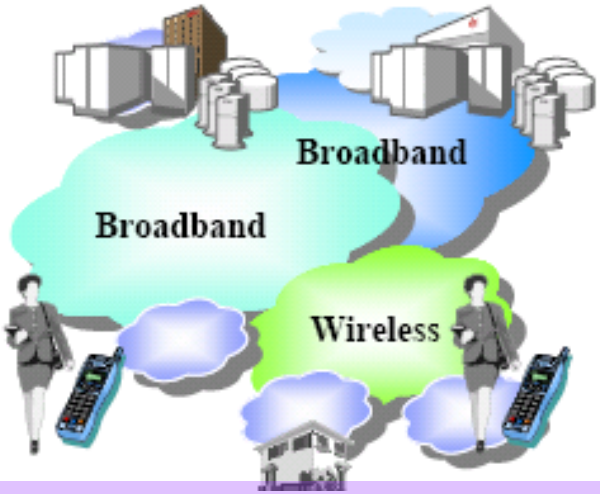
- Social lifestyle → personal lifestyle





Before	Today	Future
Computer centric	Network centric	User centric
Experts level	Trained level	Pedestrian level
Data exchange	Archieval/access	Knowledgeable

Source: MIC Japan, Fujitsu, NTT

Lifestyle drives PAN → BAN

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Social networking user growth is driving bandwidth, datacenters

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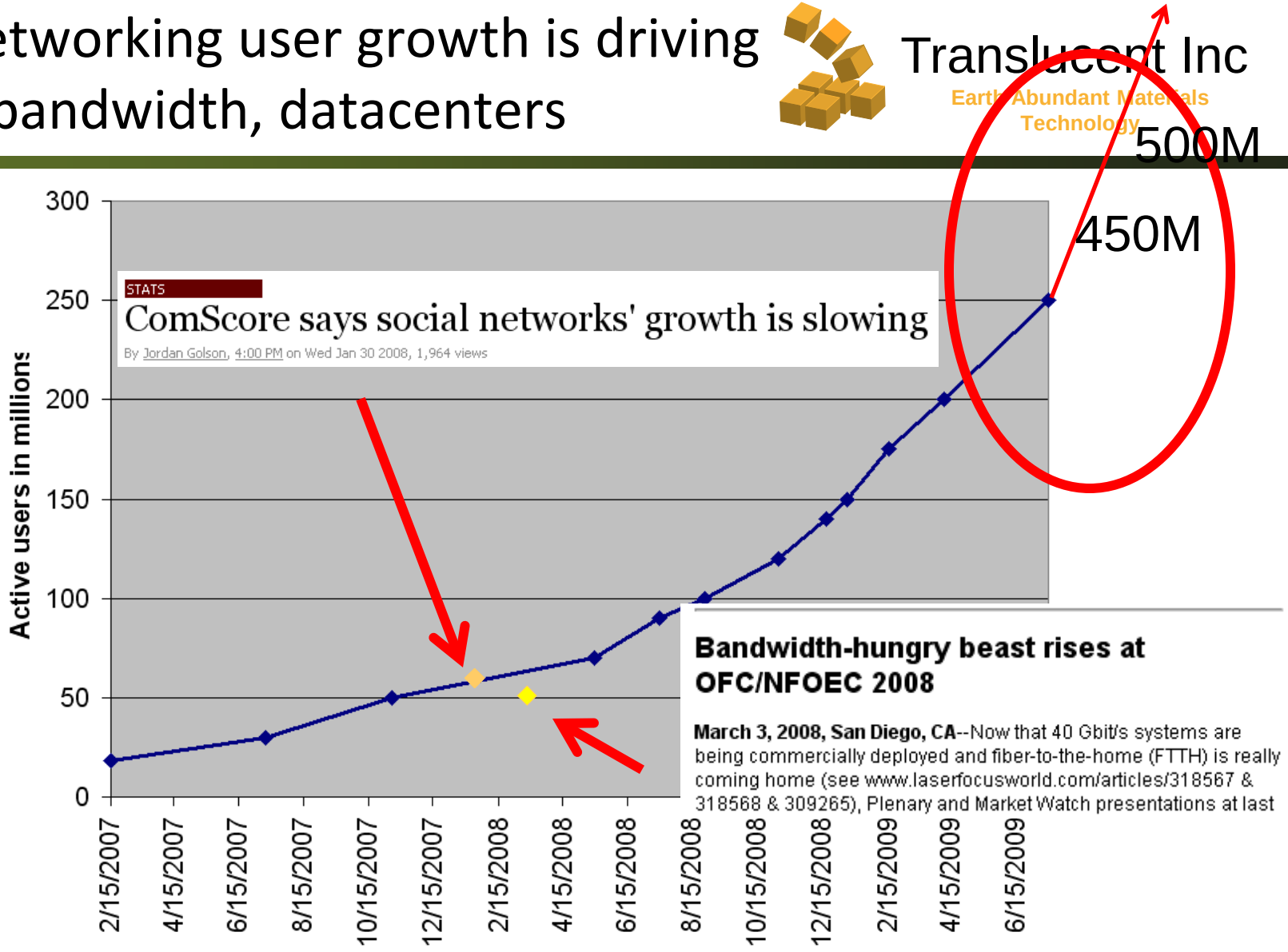

Source: Donn Lee, Facebook, Sept 09

When will the trend slow down?

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from Exa to Zetta-bytes…

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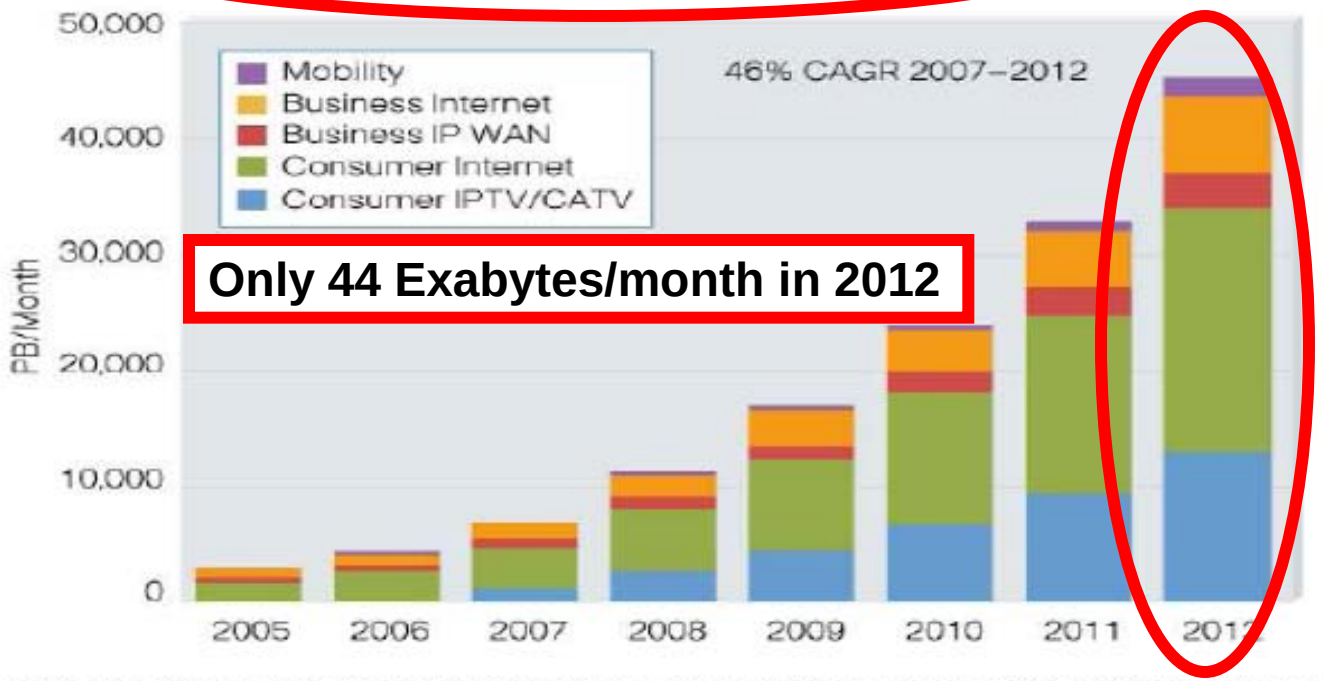
Figure 1. Cisco Forecasts 44 Exabytes per Month of IP Traffic in 2012



For more details, see the paper entitled "Cisco Visual Networking Index – Forecast and Methodology 2007–2012."
Source: Cisco, 2008

http://www.cisco.com/en/US/netsol/ns827/networking_solutions_sub_solution.html

Source: Loukas Paraschis, Cisco, OIDA OPTOmism

Driven by consumer internet…

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System capacity and network traffic

(Including voice)

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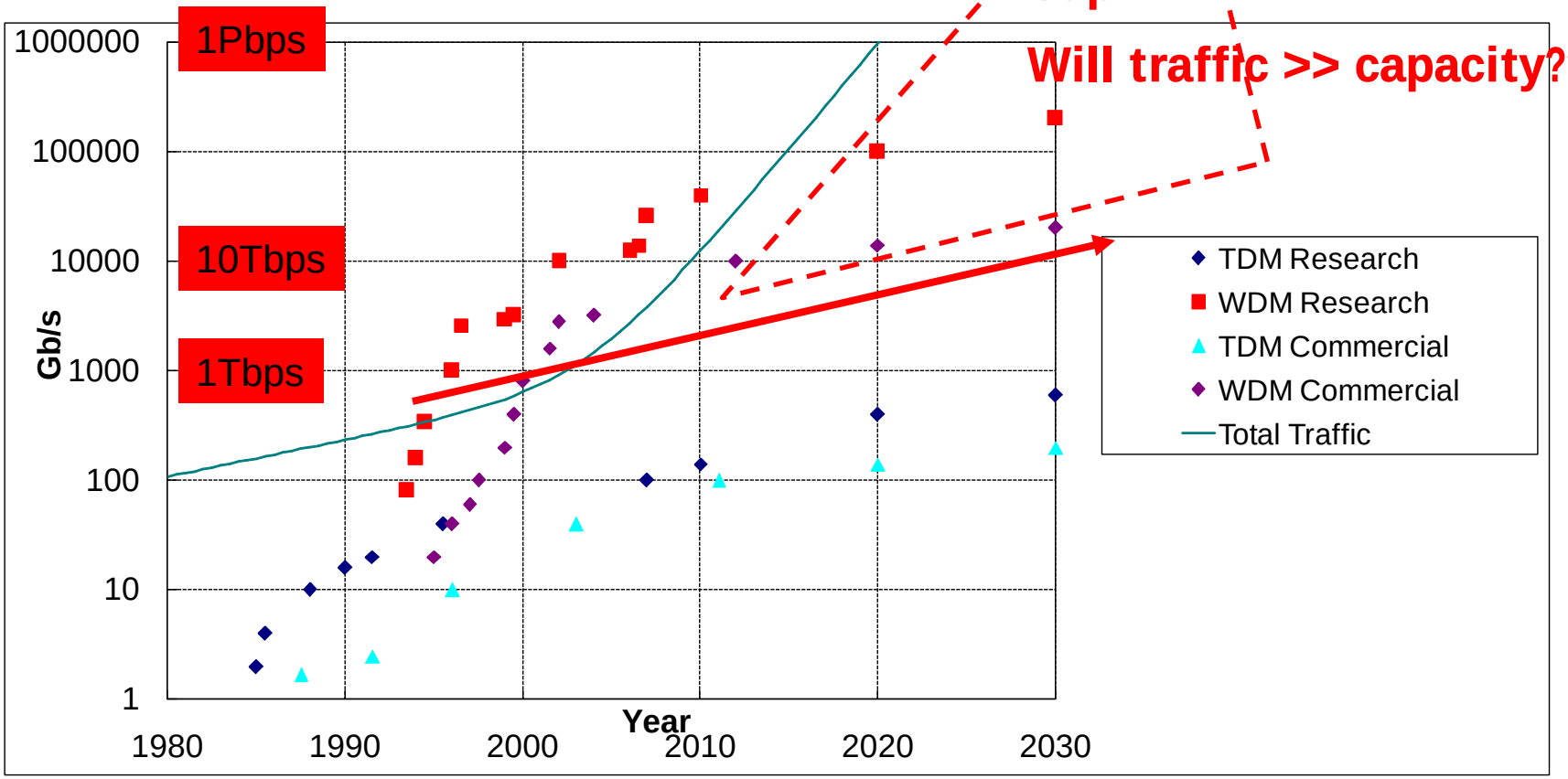
- 2010-2030 forecast trends



Source: R. Tkach Alcatel-Lucent

Will we fill the fiber optic pipes?

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System capacity and network traffic

(Including voice)

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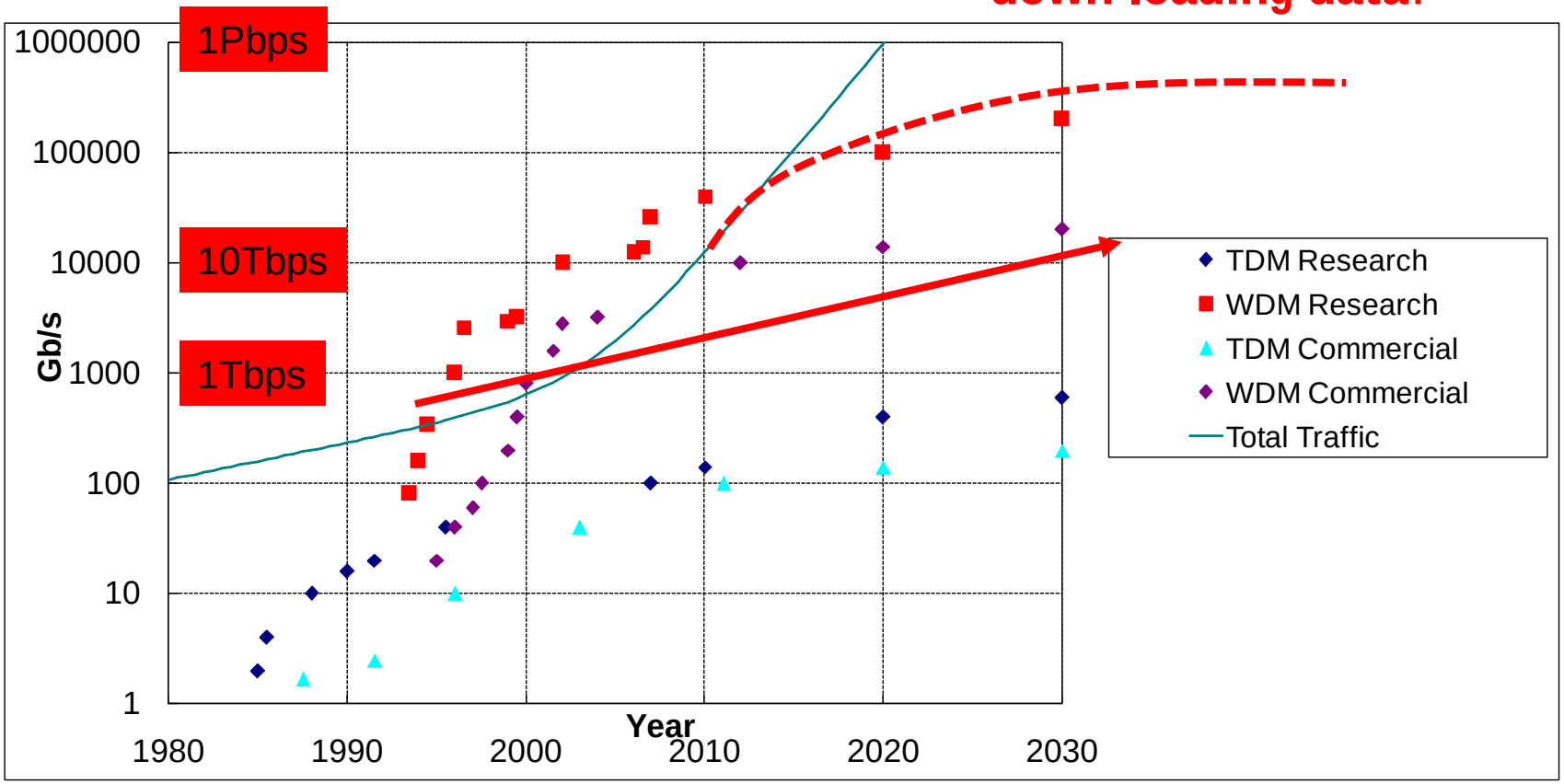
Earth Abundant Materials Technology.

- 2010-2030 forecast trends

Will the price stop us from down loading data?



Source: R. Tkach Alcatel-Lucent

Carriers will charge $/bit to slow us down…

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Networks must address energy…

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Evolve architecture quickly…

(while traffic CAGR >50%)

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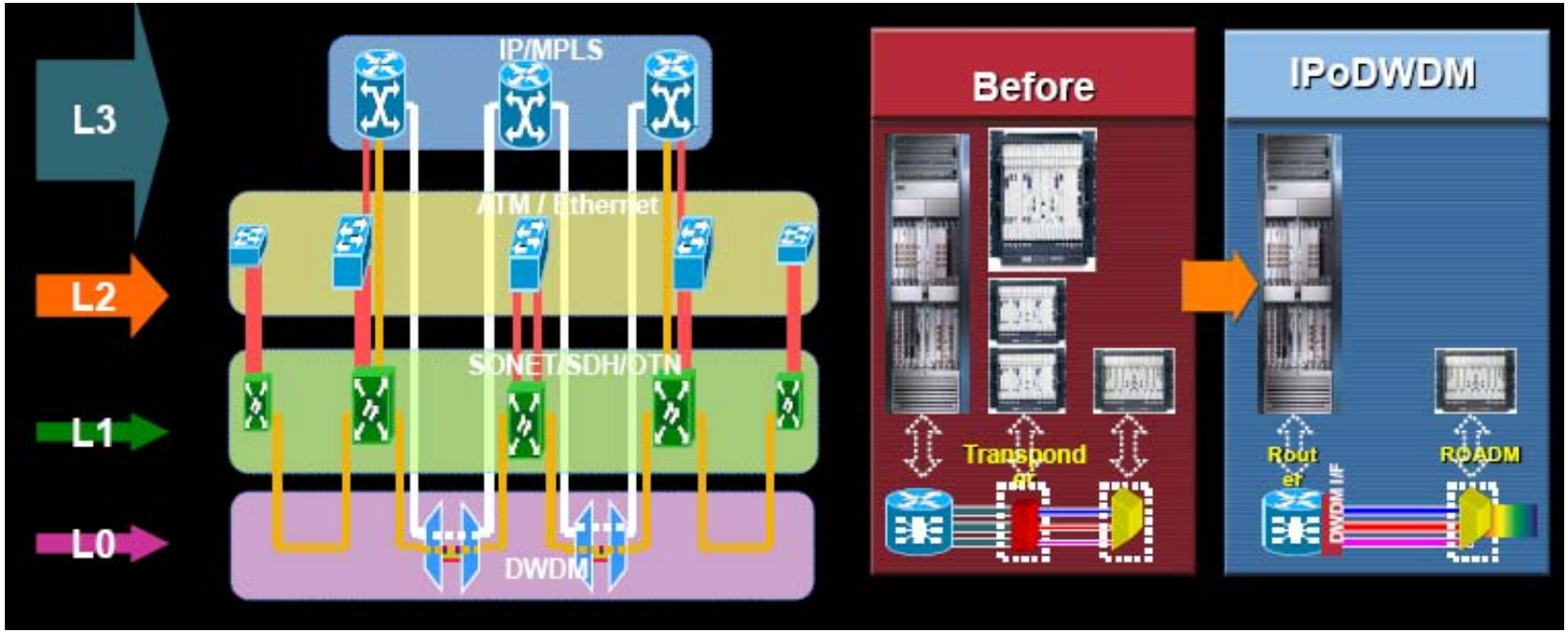
- IP over DWDM transport:
  - Eliminate unnecessary layers and minimize underutilized equipment
  - Maximize architecture and equipment scalability



Source: Loukas Paraschis, Cisco, OIDA OPTOmism

Challenge: contain energy footprint

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Cost for power and cooling in data centers

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- Year 2000
  - Raw processing 'horsepower' is the primary goal, while the infrastructure to support it is assumed ready
- Year 2006
  - Raw processing 'horsepower' is a given but the infrastructure to support deployment is a limited factor
- Year 2010
  - Three cooling challenges
    - System, rack, data center
- Year 2021

  Green designs imperative…

Source IDC: 2006, Document # 201722, "The Impact Of Power and Cooling On Data Center Infrastructure", John Humphreys, Jed Scaramella

Source: Loukas Paraschis, Cisco, DOE, OIDA OPTOmism, IBM Research, IDC

Power and cooling spending out of control…

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Broadband technology

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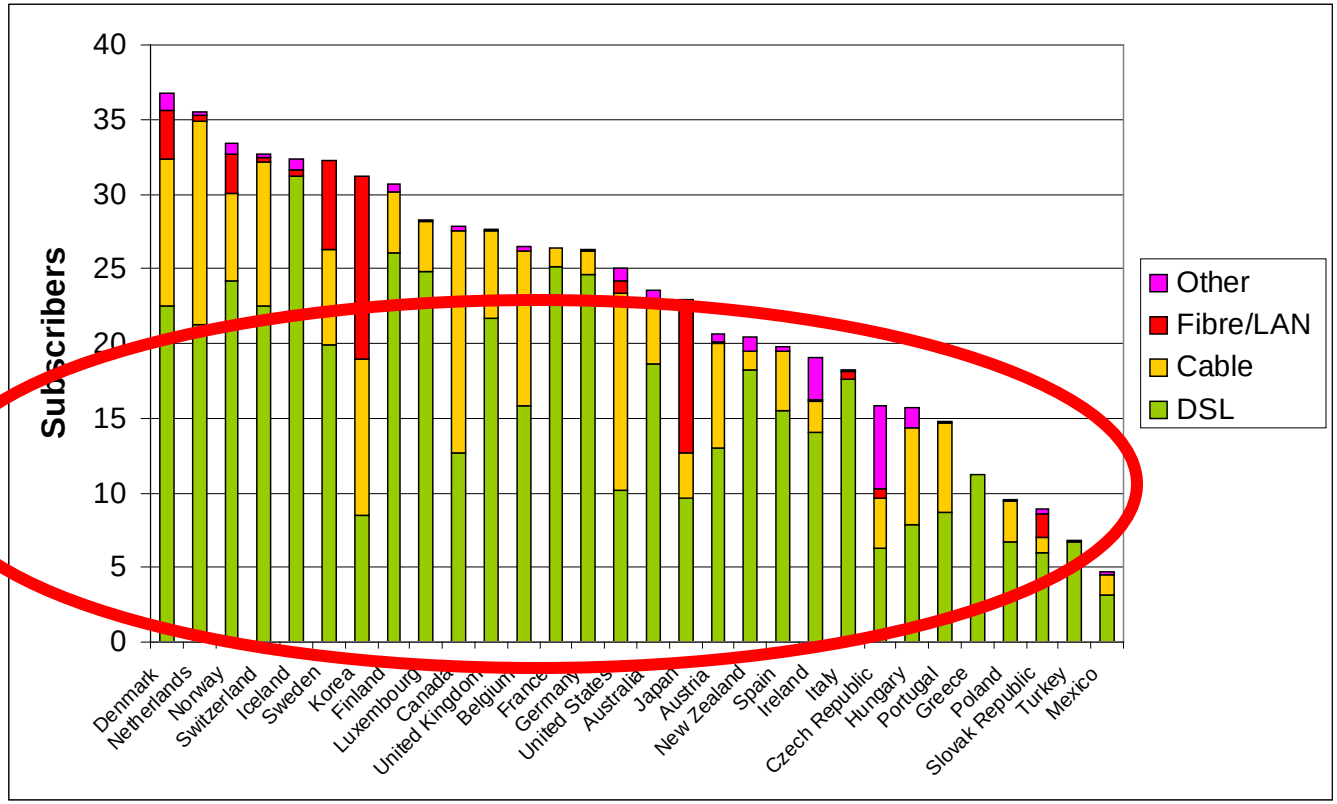
- Broadband subscribers per 100 inhabitants, by technology



Source: OECD

What is the effect if graph is mostly red?

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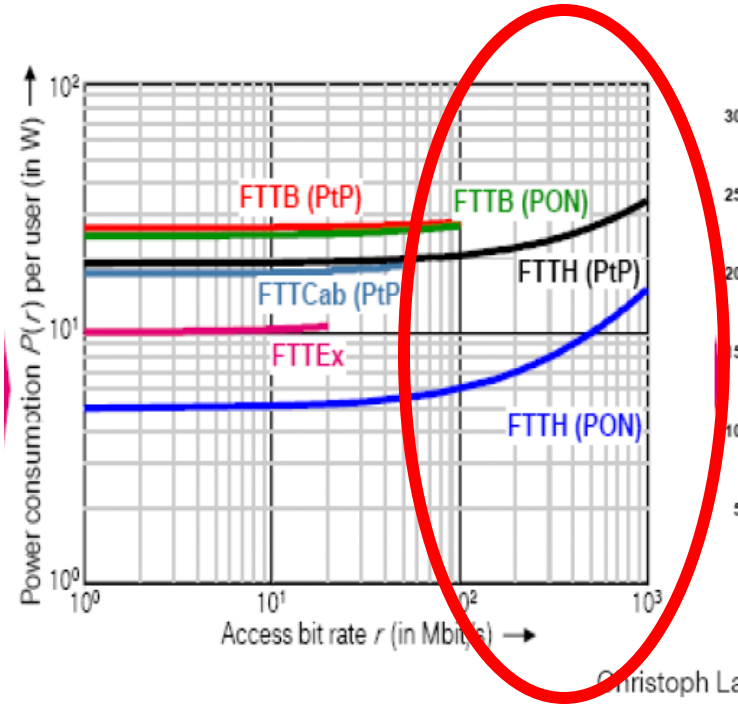
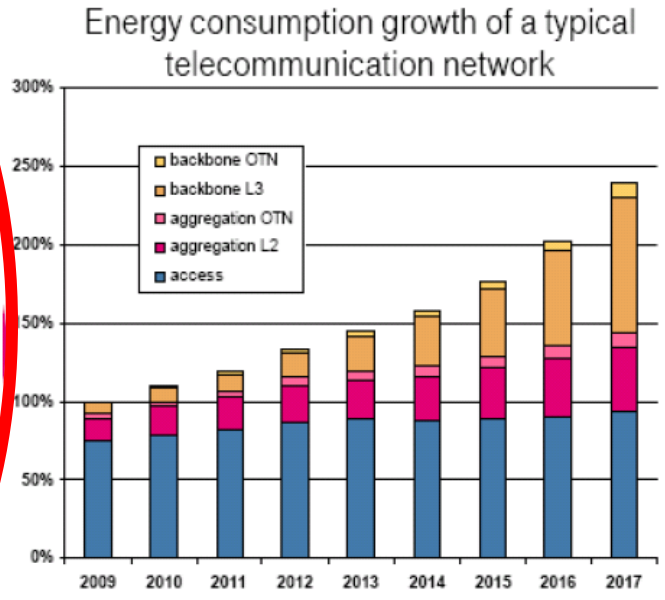
Architecture evolution – FTTH access





Christoph Lange, Andreas Gladisch
Deutsche Telekom AG, Laboratories

Source: Loukas Paraschis, Cisco, Lange, Deutsche Telekom AG

Power consumption expected to rise fast…

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Photonic integrated circuits save power

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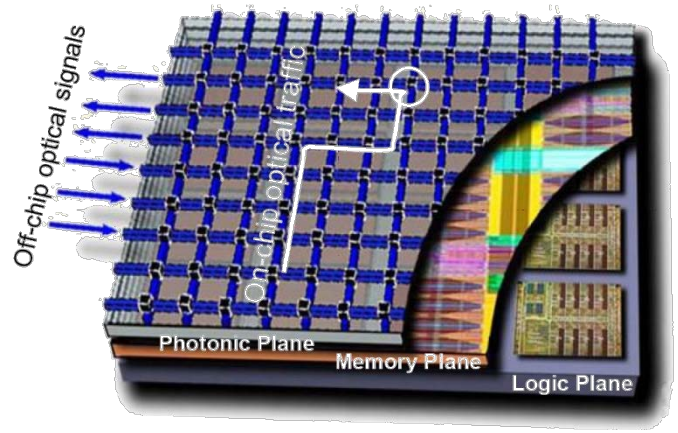
- Important roles for green photonics in reducing power consumption in communications and computing
  - **Short term** – further deployment and upgrading of optical communications links with lower mW/Gb/s, also leads to reduced cooling requirements and improved cooling capability
  - **Medium and Long term** – new computing hardware architectures employing optical interfaces between processing, logic, and memory will lead to higher flops/W



Sources: Lightwire, IBM

Tighter integration leads to lower power

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Photonics will become integrated...

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Moore's Law → photonics to follow?

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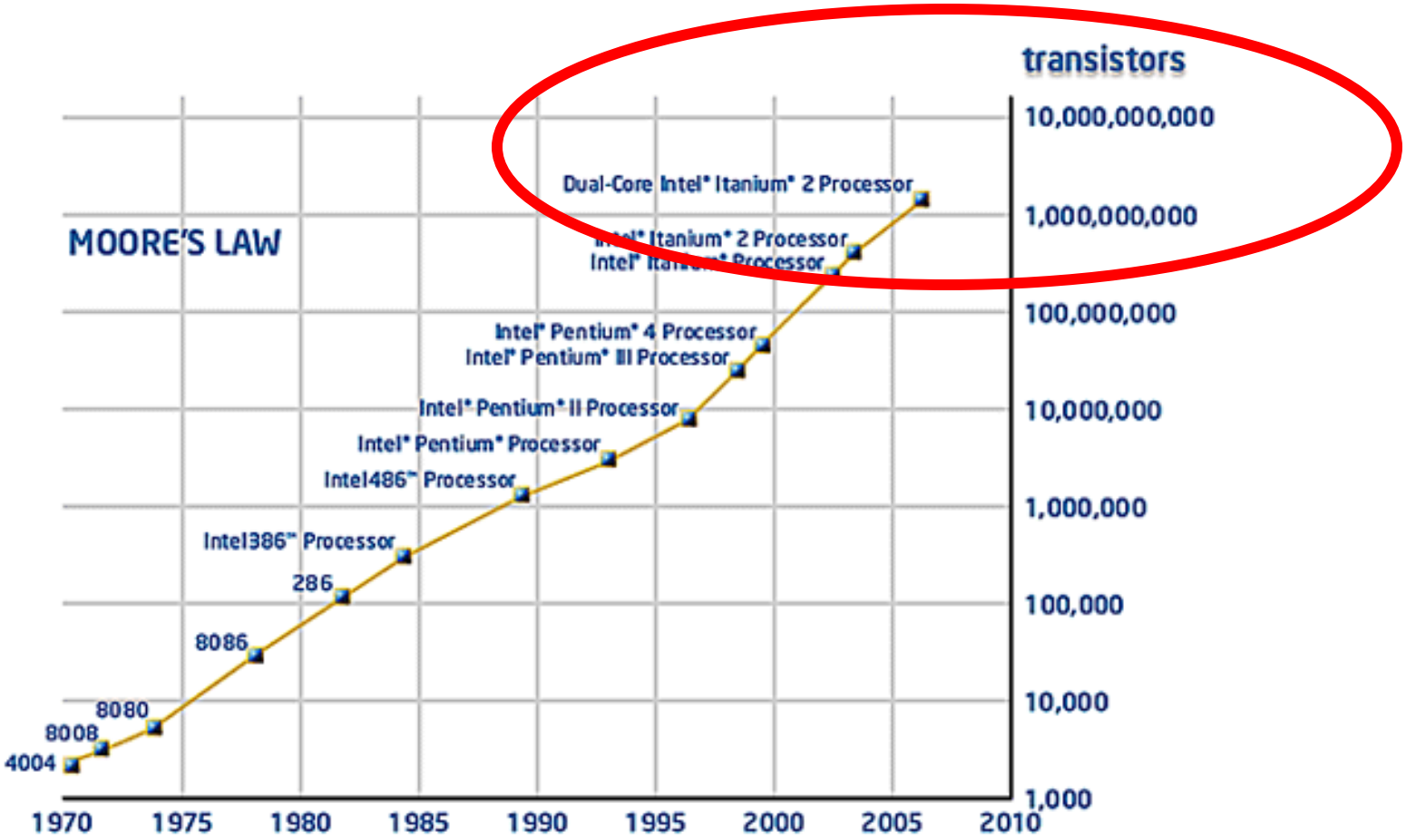

Sources: UCSB, OIDA Photonics Integration Forum, Intel

CMOS very successful → can we learn?

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PIC trends over 3 decades

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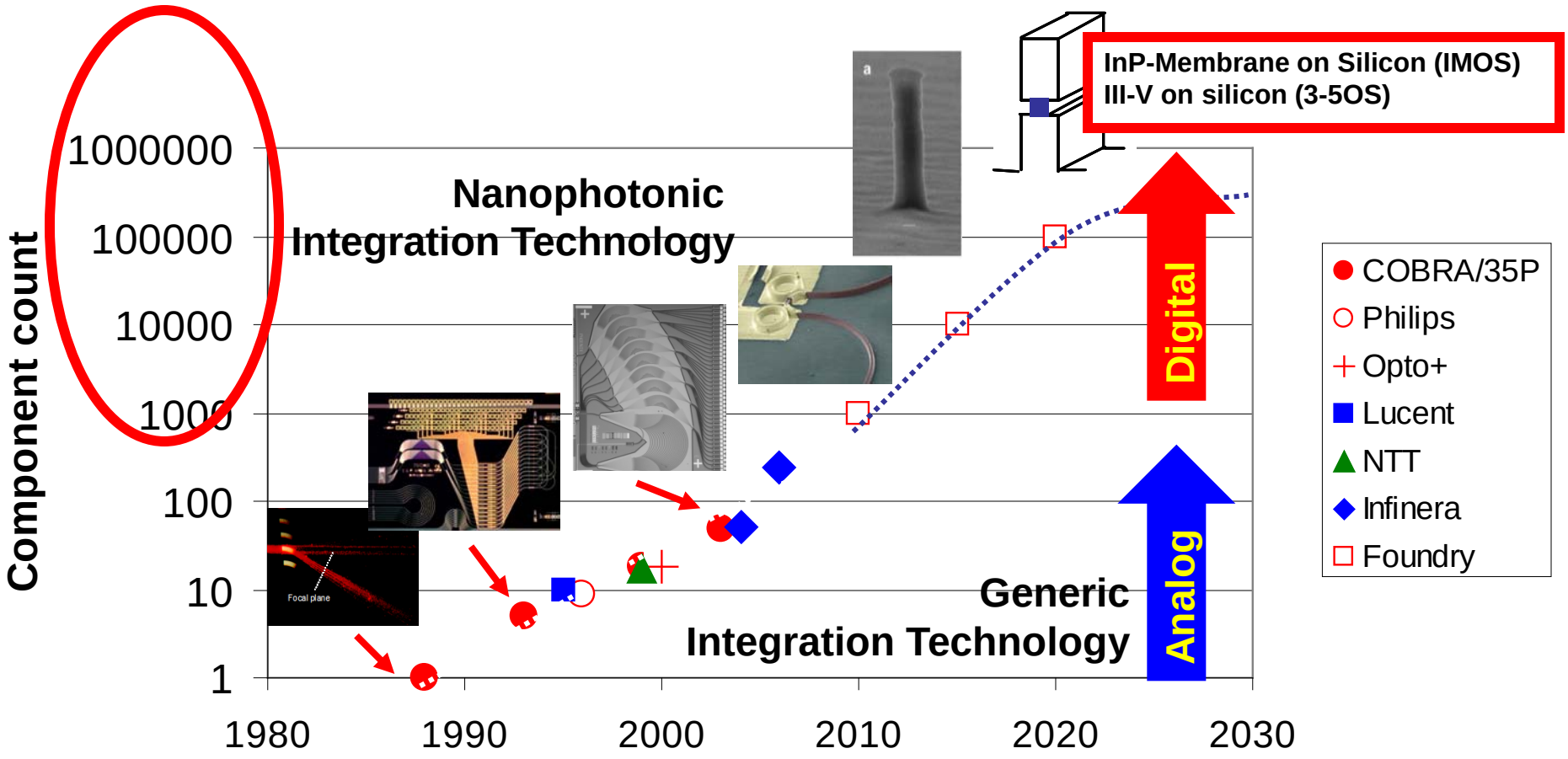

Source: Meint Smit, TU/e OIDA forum Oct 2008

Photonics is expected to become digital…

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Integrated photonics over 4 decades…

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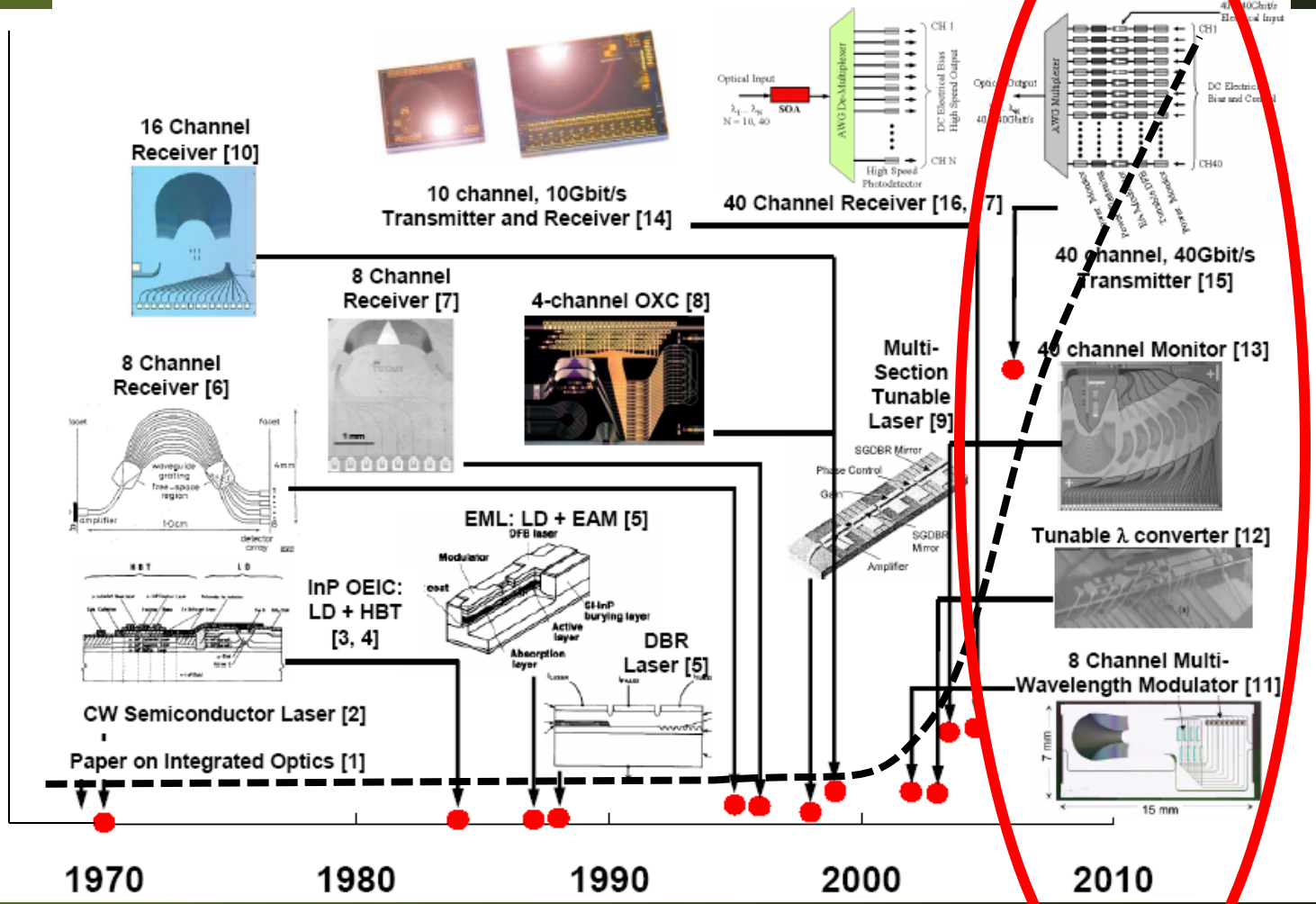
Courtesy of
R. Nagarajan & M. Smit
(LEOS Newsletter, 2007)

1.S.E. Miller, 1969
2.I. Hayashi, 1970
3.J. Shibata, 1984
4.O. Wada, 1986
5.T. Koch, 1991
6.M. Zirngibl, 1995
7.C. Steenbergen, 1996
8.C. Herben, 1999
9.L. Coldren, 2002
10.Y. Yoshikuni, 2002
11.Y. Suzaki, 2002
12.M. Masanovic, 2003
13.ASIP/III-V, 2004
14. R. Nagarajan, 2005
15. R. Nagarajan, 2006
16. M. Kato, 2007
17. R. Nagarajan, 2007

Not shown (EDG-WDM):

V. Tolstikhin, 44-channel dynamic equalizer, 2002;
V. Tolstikhin, 44-channel power monitor, 2003;
A. Densmore, 32-channel receiver, 2005;
V. Tolstikhin, 3-channel ONU triplexer, 2005



Sources: OneChip Photonics; Valery Tolstikhin

Poised for big impact in fiber comms

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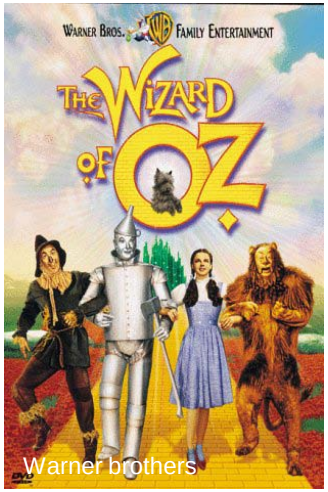
Consumer → must be ‘green’



Warner brothers


southern4life.blogspot.com

New decade opportunities

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- System integration
  - Take a display and incorporate it into a ‘cool’ product
    - iphone, fridge, golf cart …
- Modify for niche markets
  - Medical - resolution, bit depth …
  - Defense – ruggedness, portability …
  - Sports – weight, form factor …

3D?

HDTV

COLOR

B&W

We see things in 3D!

Sources: Colorlink, RCA, Motorola, Sony, Philips

System integration, niche, and 3D?

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Displays going green & energy efficient

Translucent Inc
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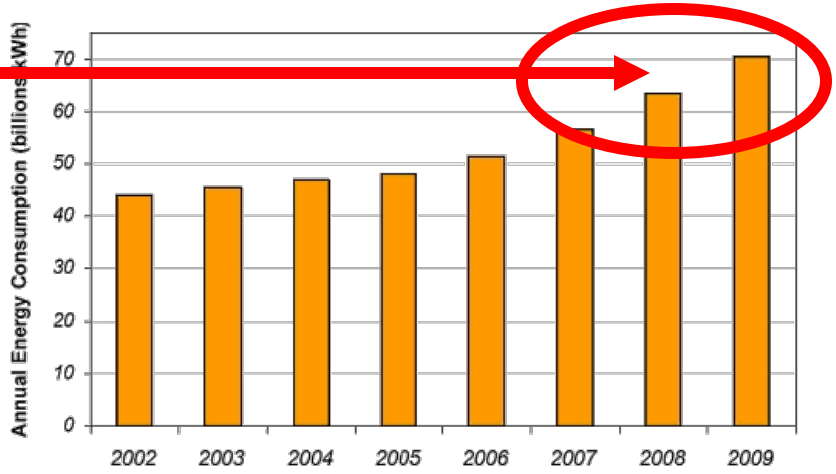
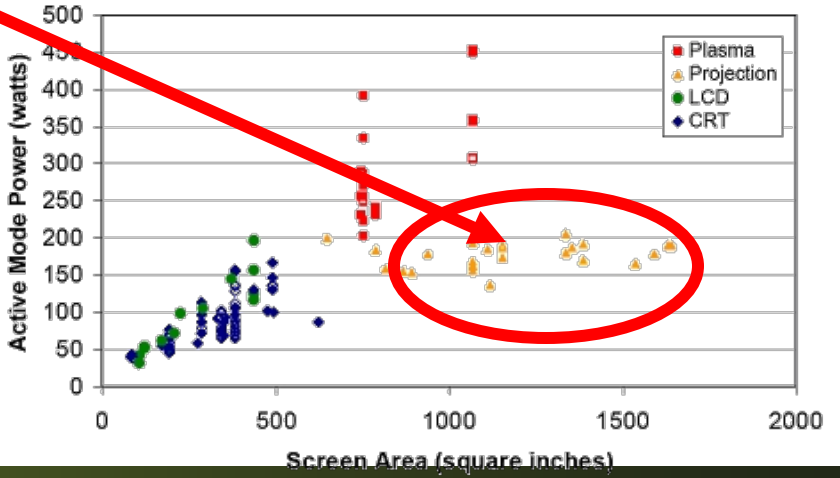
- US TVs consumed ~70 billion kWh
  - ~4% residential electricity use
- TV power consumption scales with screen size
  - Projection lower power than plasma
- Laser projection TV offers major power savings
  - For 60”-65” class TV
    - Plasma 524W, LCD 525W, Laser projection 135W
- Sony XEL-1 OLED TV power consumption matches trend
- Mature but rapidly disappearing CRT TVs are relatively efficient
- Plasma makes comeback via 3D!
  - Fast response times needed





Source: NRDC

Projection and OLED TVs save power

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OLED displays (green)

have caught imagination of the public…

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- OLED displays although successful in small displays → struggling with TV/large displays…
  - The performance attributes of OLED displays – thinness, high contrast, high response speed, … allow designers to differentiate their product

Sources: Phil Wright, OIDA

Sources: Sony, Nokia, iRiver

Organic LED…so we don't use pesticide

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Projection photonics

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Projection: new diode laser market?

Translucent Inc
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- Consumers will find new opportunities to utilize
- Being able to enhance life at anywhere, anytime, anyplace

Sources: OIDA, Novalux, TI

New lifestyle using laser technology

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Challenges for the display industry…

Translucent Inc
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- What exists → 2” display in 8oz package
- What the market desires → 20” display in 8oz package

2”

Sources: OIDA, TI, TNS Research in Japan, August 2004

Projection offers one solution

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Projection technology roadmap

Translucent Inc

2000 2004 2008 2012 2016

Traditional projection technologies

Class: mobile
Use: travel in pc case
Technology: UHP

~15L/lb

400L

>4x (increase)

27 lb

>10x (decrease)

1700L

~850L/lb

2 lb

Green diode laser 515nm

Pico-projector PDA w/direct LD

Future projection technologies

Class: pocket
Use: wearable
Technology: LED, Laser

~50L/lb

20-50L

>4x **(increase)**

1 lb

>10x (decrease)

~800L/lb

80-200L

0.1 lb

Weight (lb)	30	20	10	1		0.5		0.1
Volume (cu-in)	200	100	50		30	25	20	15

Source: OIDA

Challenge to shrink and be brighter

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Blue-green material progress

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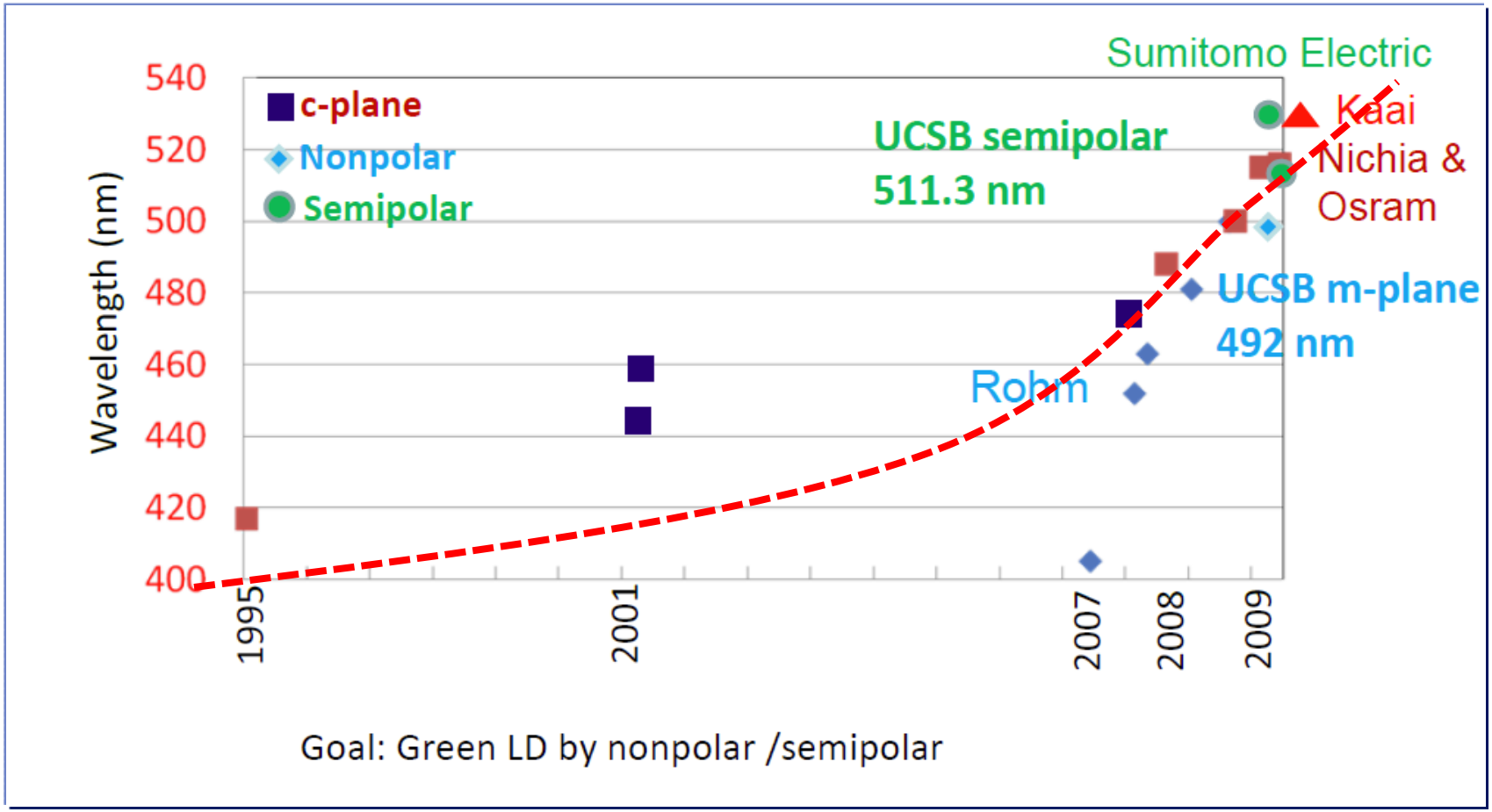
Earth Abundant Materials Technology.



Source: OIDA research, Kaai, UCSB

Green laser diode → efficient green LEDs

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LED market trends

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HBLED decade trends

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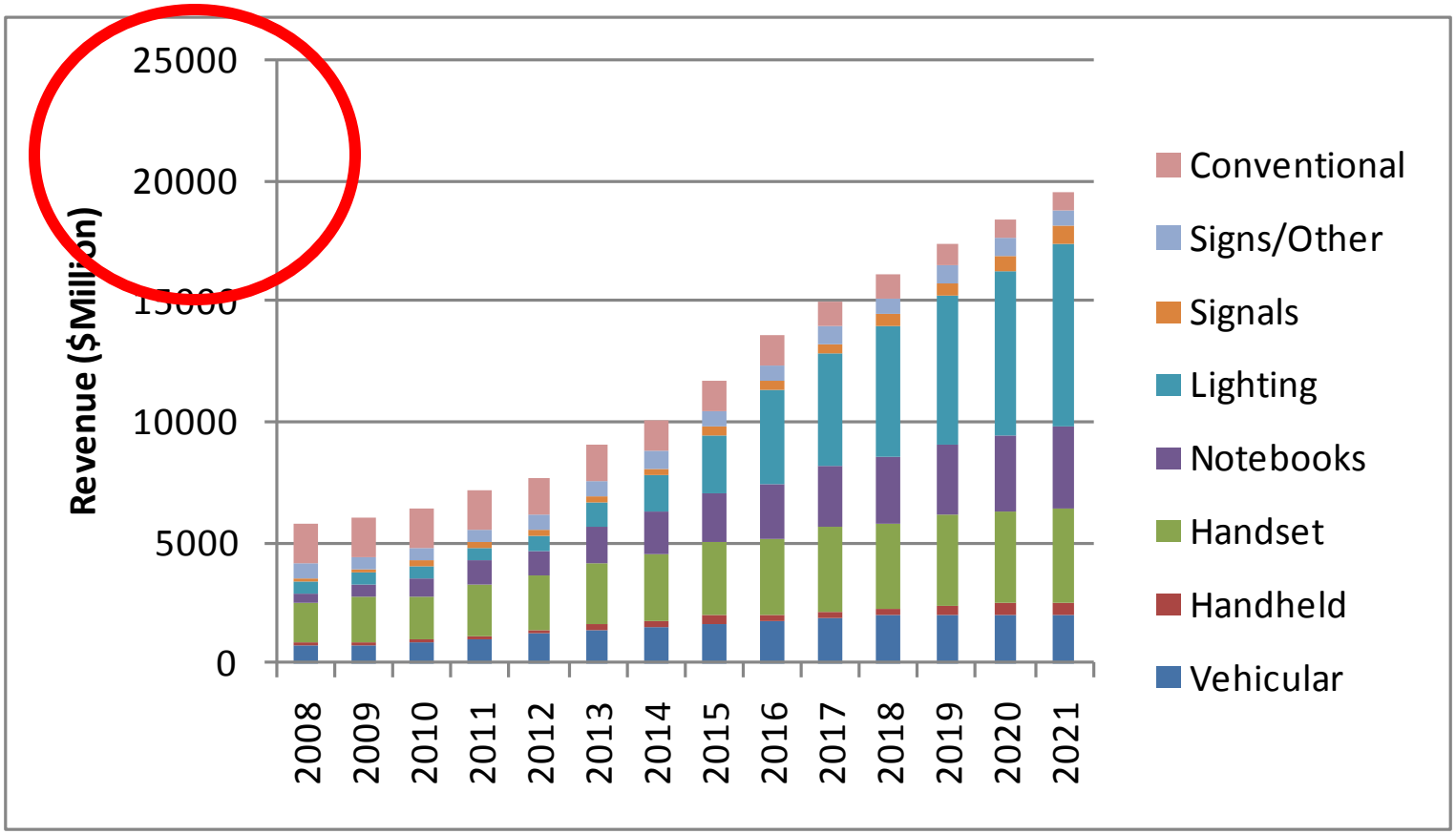
- Industry nearing $20B, and lighting >$7B, in 2021



Source: OIDA research

Driven by consumer products

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Lighting trends for LEDs

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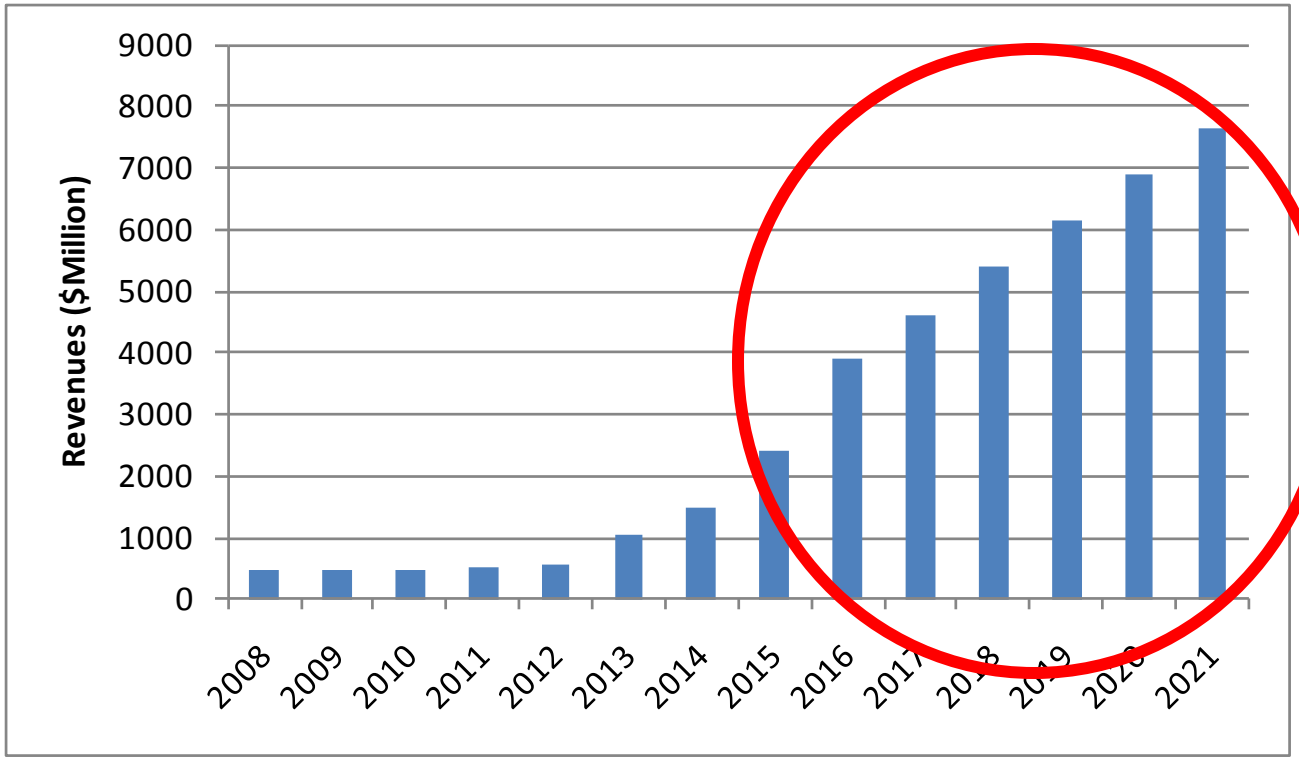
- Global revenue 2009 achieved $480M
- Highest CAGR in any category next decade (24%)



Source: OIDA research

Strong growth expected → legislation driven

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Low income: light to educate

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- Electric light transforms the lives of the poor, making it possible for families to stay active - and children to study - after night falls. But electricity is scarce in many developing countries; millions of villages are far from the grids, and power is expensive. Now the ***Light Up the World Foundation*** has found a way to illuminate whole villages with less electricity than is used by a single 100 watt bulb. Combining simple pedal-powered electric generators with wind turbines and with cutting edge technology from light-emitting diodes it has won a Rolex Award for Enterprise. Already working successfully in ***Nepalese villages***, it is set to spread around the world.

Source: Philips Lumileds, Photos Courtesy of Light Up the World and PICO Power, www.ourplant.com, OIDA

Positive impact on new technology

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Momentum…

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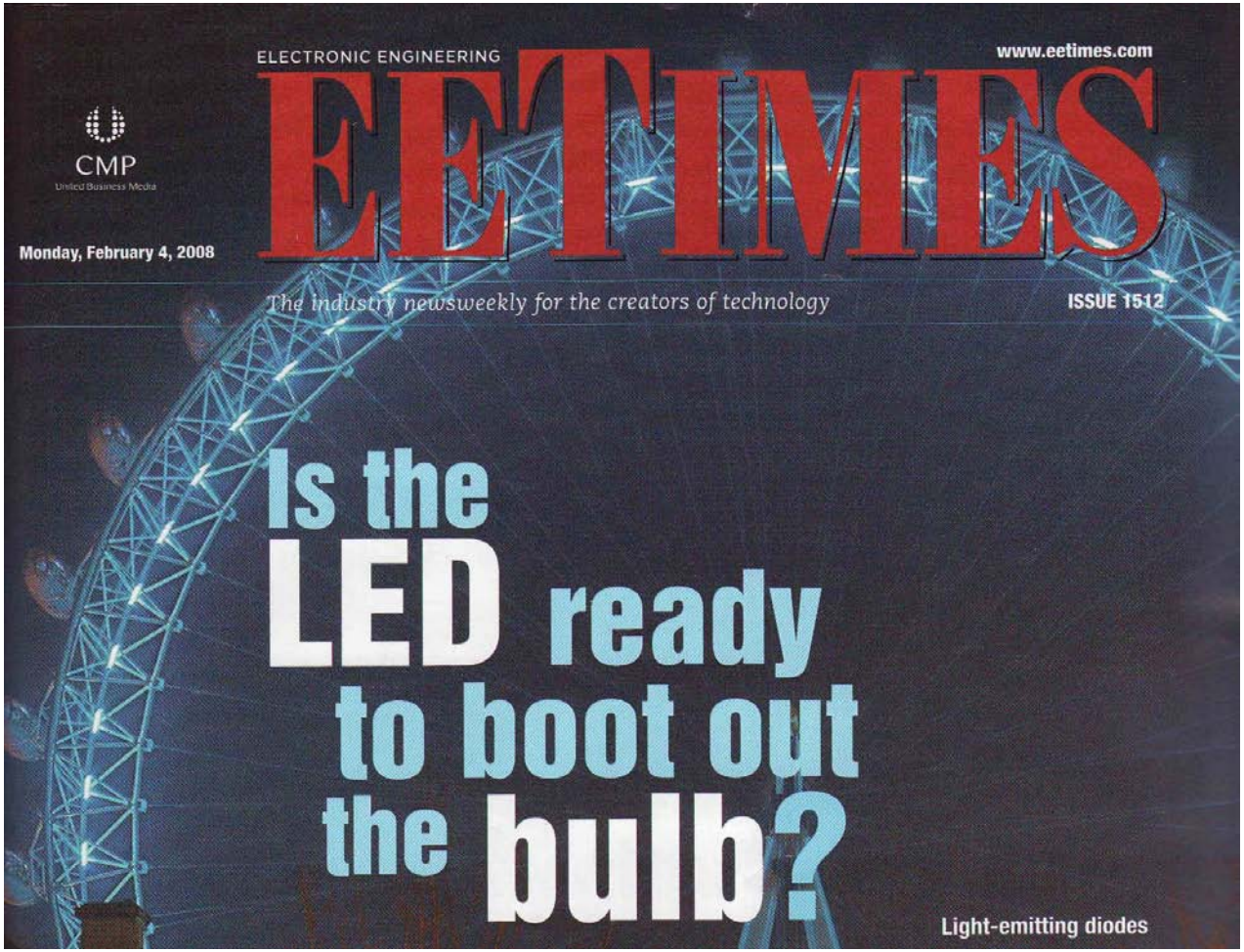

Source: OIDA research

Questions are now being asked…

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In a decade…

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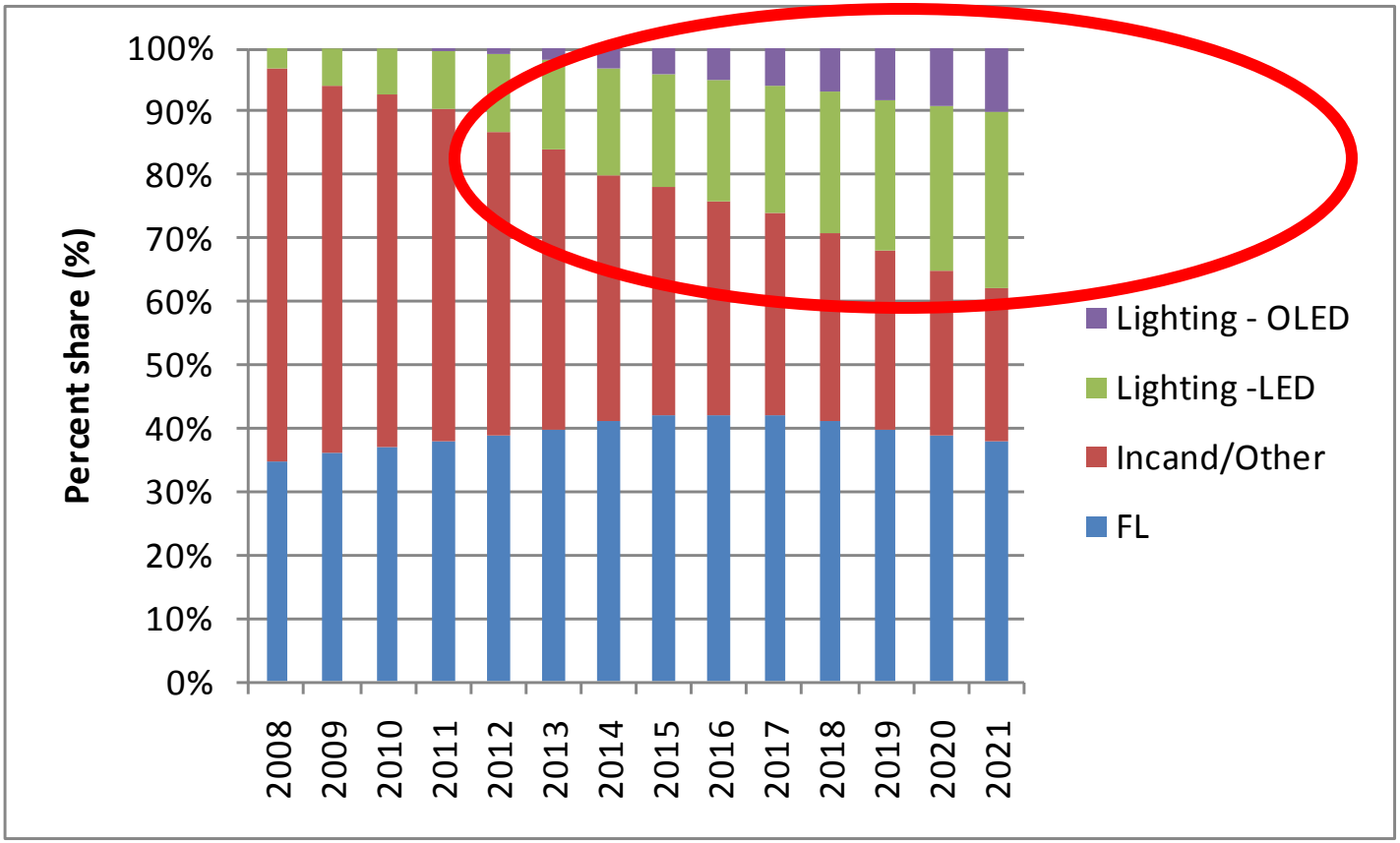
- Combined LED/OLED will grow to ~43% of lighting market by 2021



Source: OIDA research

Will the G20/G8 ban Hg/Incand in 5yrs???

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Lighting: crucial to save energy

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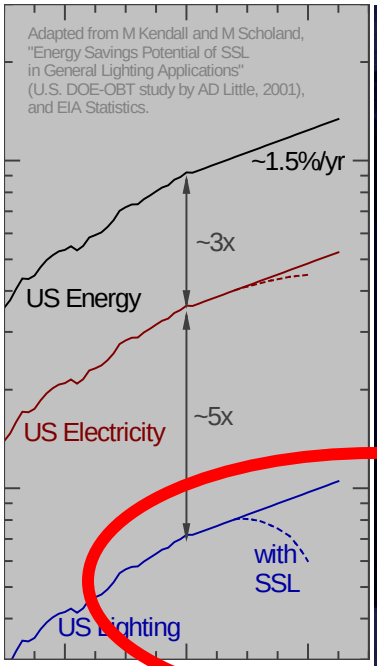
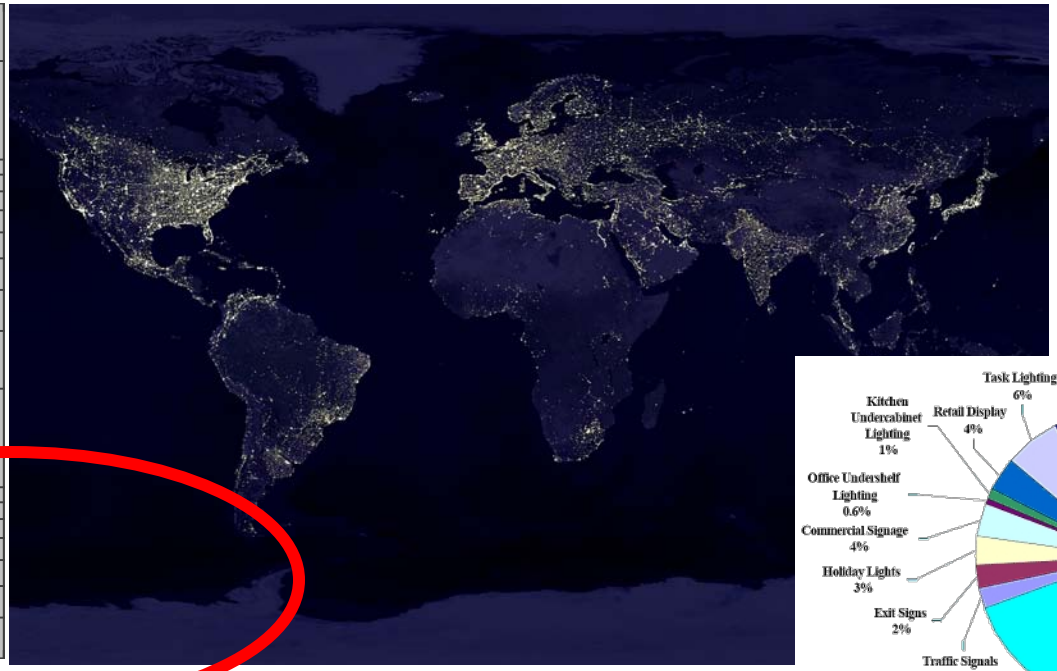
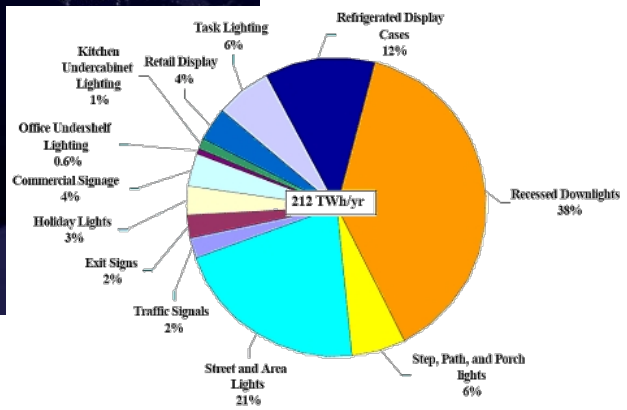
- U.S. electricity consumption could fall by 300TWh/yr by 2020
  - 212Twh/yr if all sockets converted to LEDs (>2% energy







Source: Jeff Tsao, Sandia National Laboratories, DOE

Saving energy is clean (and green)…

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In a decade: LED wallpaper…

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Earth Abundant Materials Technology.

- LED lighting utilizing silver-based conductive patterns and graphite-based series resistors that are printed in a single pass in a rotogravure process (roll to roll).
- SMD LEDs can then be mounted with conductive glue in an automated process.
- The process has been designed for flexible substrates up to 200µm gauge.
- Alcan believes the process can open up new applications for LEDs

Source: OIDA research, Alcan, Maurer 'Rose on the wall' , Jannon, UKDL

Is this more light or less? Green or wasteful?

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Photonic (SSL) lighting progress

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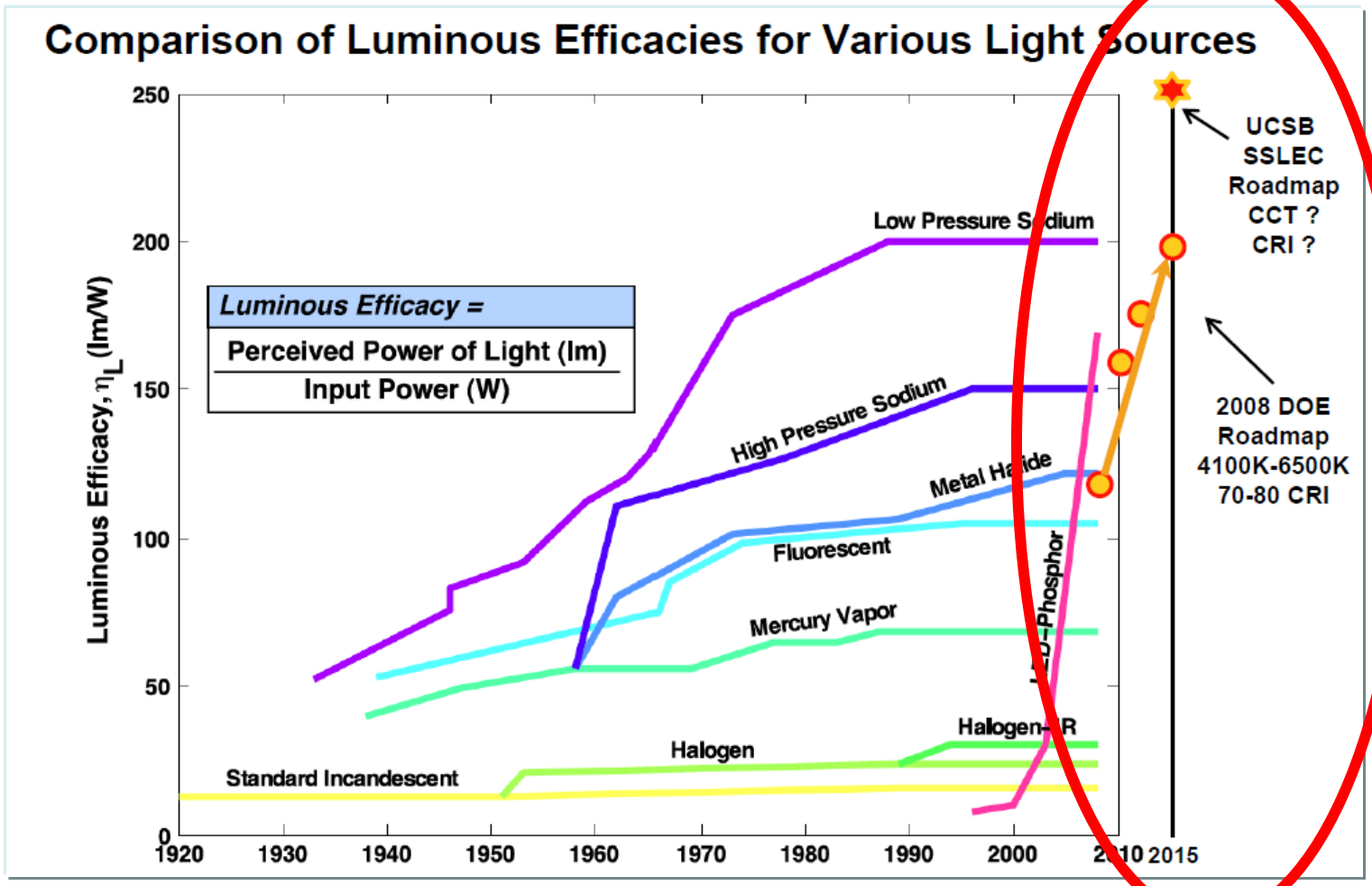

Sources: Kaai,UCSB

LED performance faster than anticipated…

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Sensors will be utilized more...

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Optical sensors in key green roles

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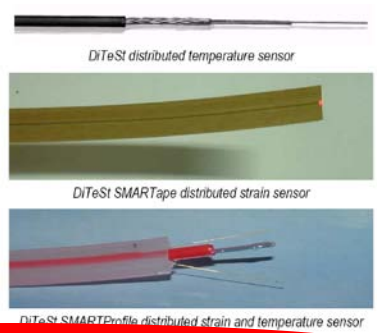
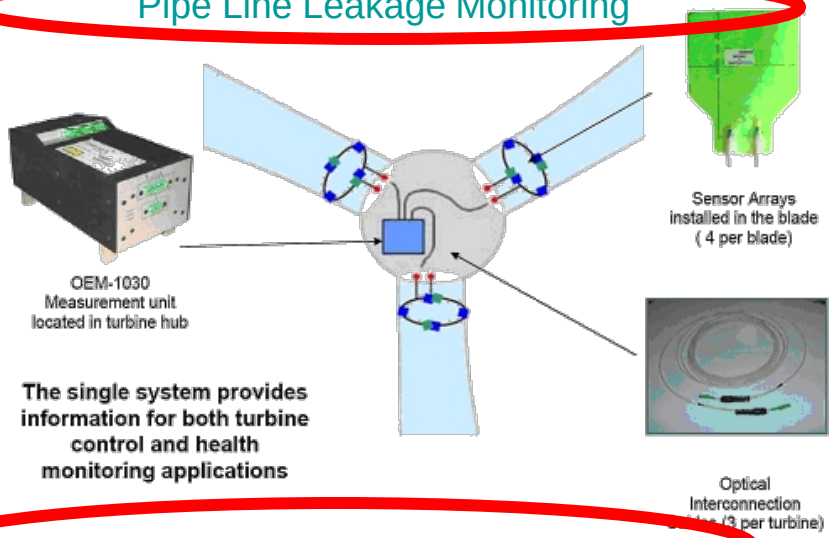
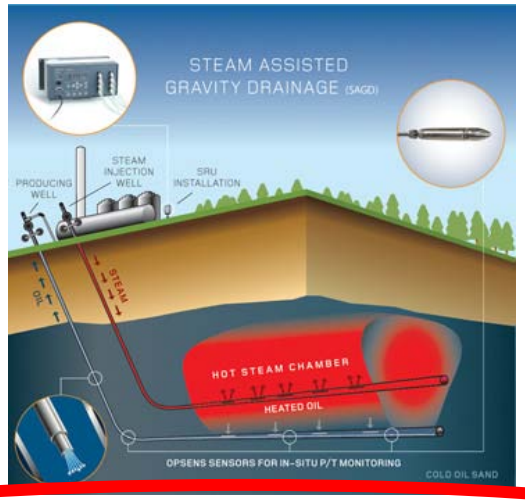


Pipe Line Leakage Monitoring



Fiber Optic Sensors for Wind Turbine Control



Fiber Optic Sensors for Oil Extraction

LIDAR for Wind Turbine Control

Sources: Smartec, Opsens, Catch the Wind, Insensys

Very broad application space

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Solar photovoltaic (pv)

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In 10yrs, USA joins in…

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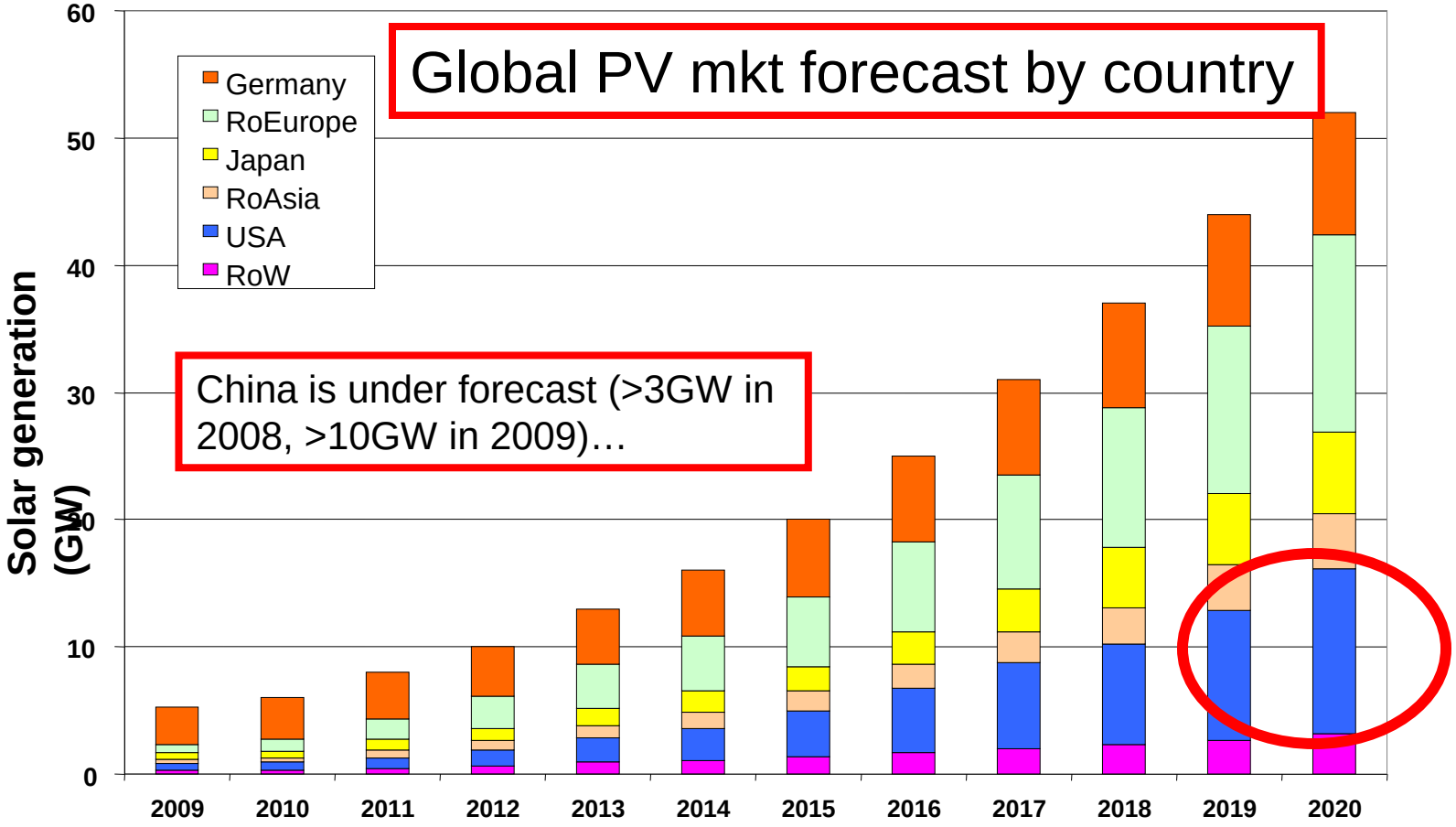

Source: OIDA, EPIA, Navigant Consulting, NREL, European Commission, IOA

50GW → now viable alternative for power

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The hills are green….oops

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- 11MW Serpa, Portugal
- Project led by GE
- 52,000 panels 200 watts each
- Project cost: 75 million euros
- Installed in six months
- Operational since Jan 2007

Source: OIDA, EPIC, eupvplatform.org, EPIA

Will environmentalists complain…absolutely

lebby@translucentinc.com

Source: www.silexsolar.com.au

End of the line – a finished solar module

lebby@translucentinc.com

Source: www.silexsolar.com.au

Solar cell process lines in operation

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While many drive efficiencies…

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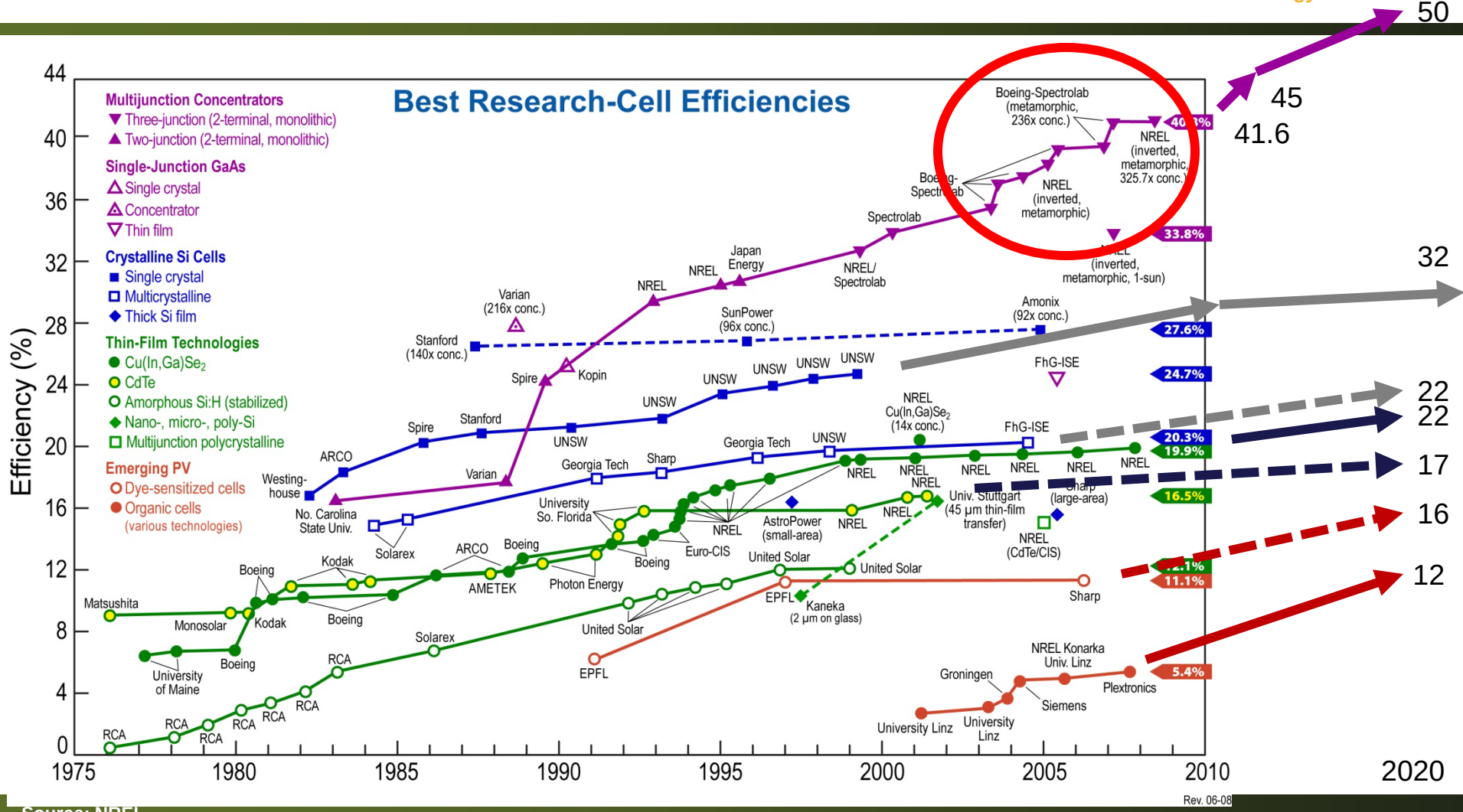
%



50

45

41.6

32

22

22

17

16

12

Source: NREL

Is higher cell efficiency our only option?

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Dense array…

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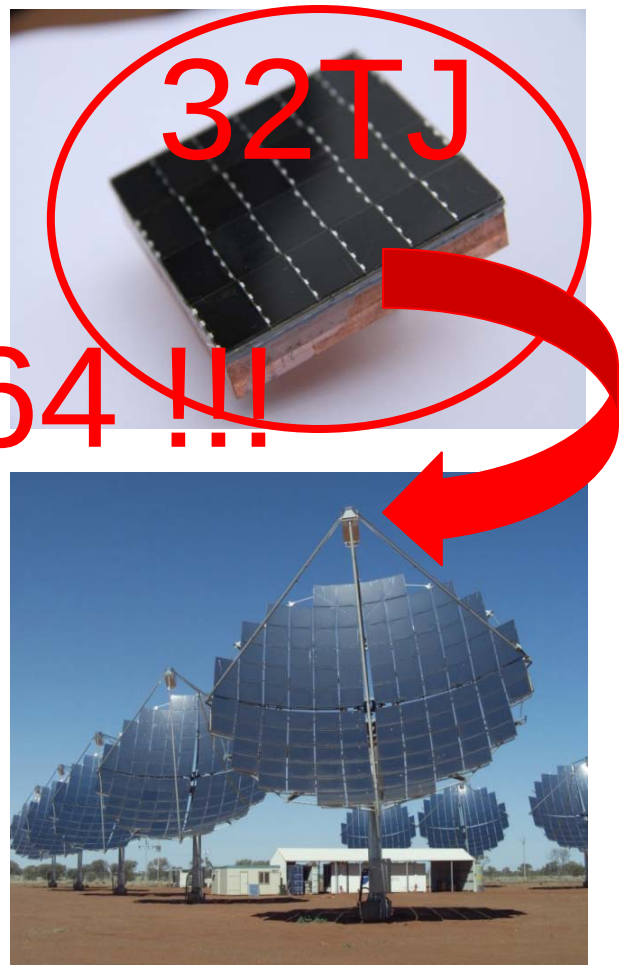
- Advantages of dense array technology:
  - Based on ultra-high efficiency triple junction cells
  - Low upgrade cost (now ~40% cells, future ~50%)
  - Low maintenance solution
  - Lower PV cell operating temperature for dense
- Array technology (active vs passive cooling):
  - Extends lifetime of cell
  - Higher reliability of module
  - Higher conversion efficiency
- Flexibility
  - Dish CPV – first product range
  - Heliostat CPV – next generation product
  - Potentially lowest cost solar power technology (LCOE)



2 decades of CPV experience…

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Industry must keep costs down…

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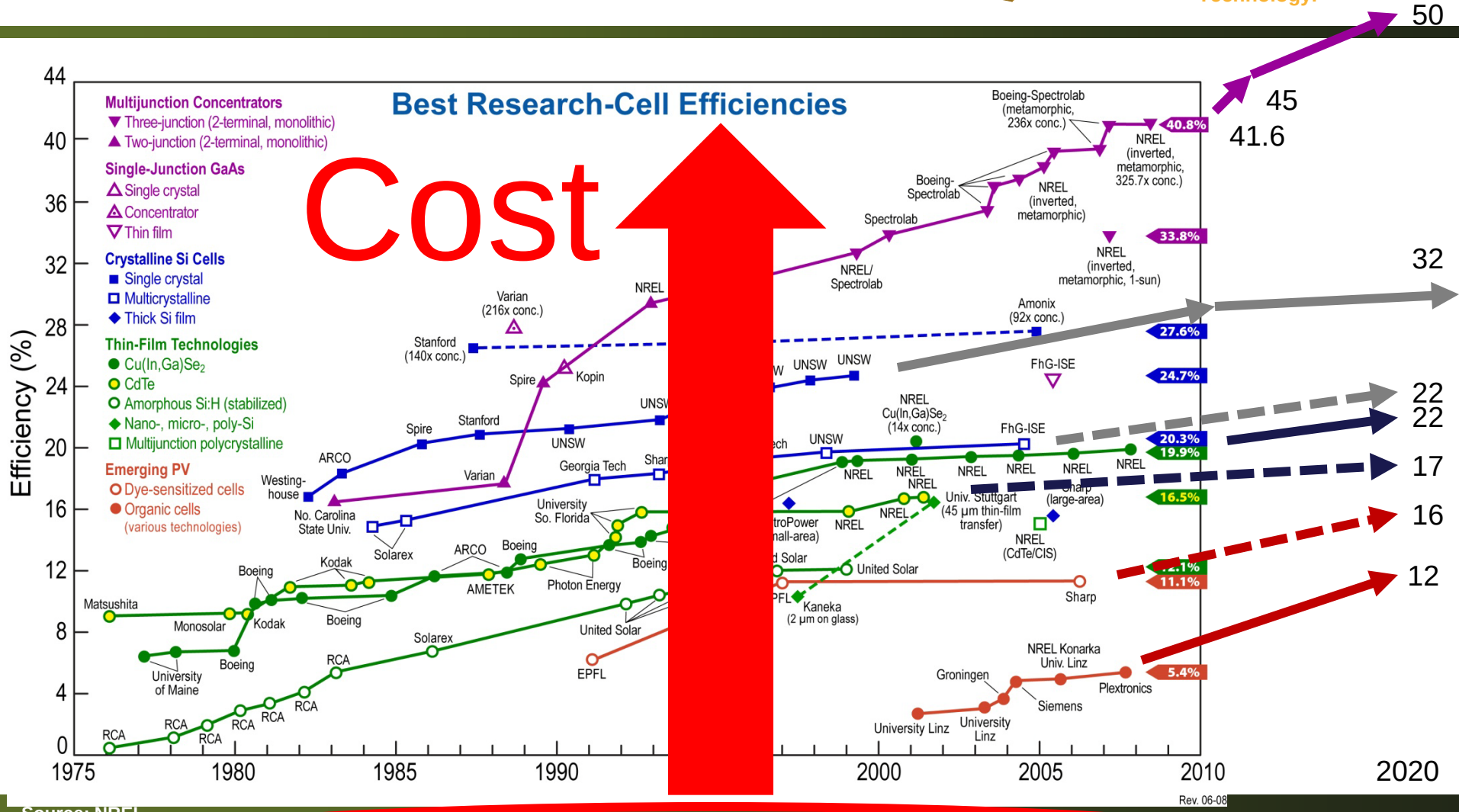
%



Source: NREL

Higher efficiency → higher cost of the cell

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Translucent is looking at cost…

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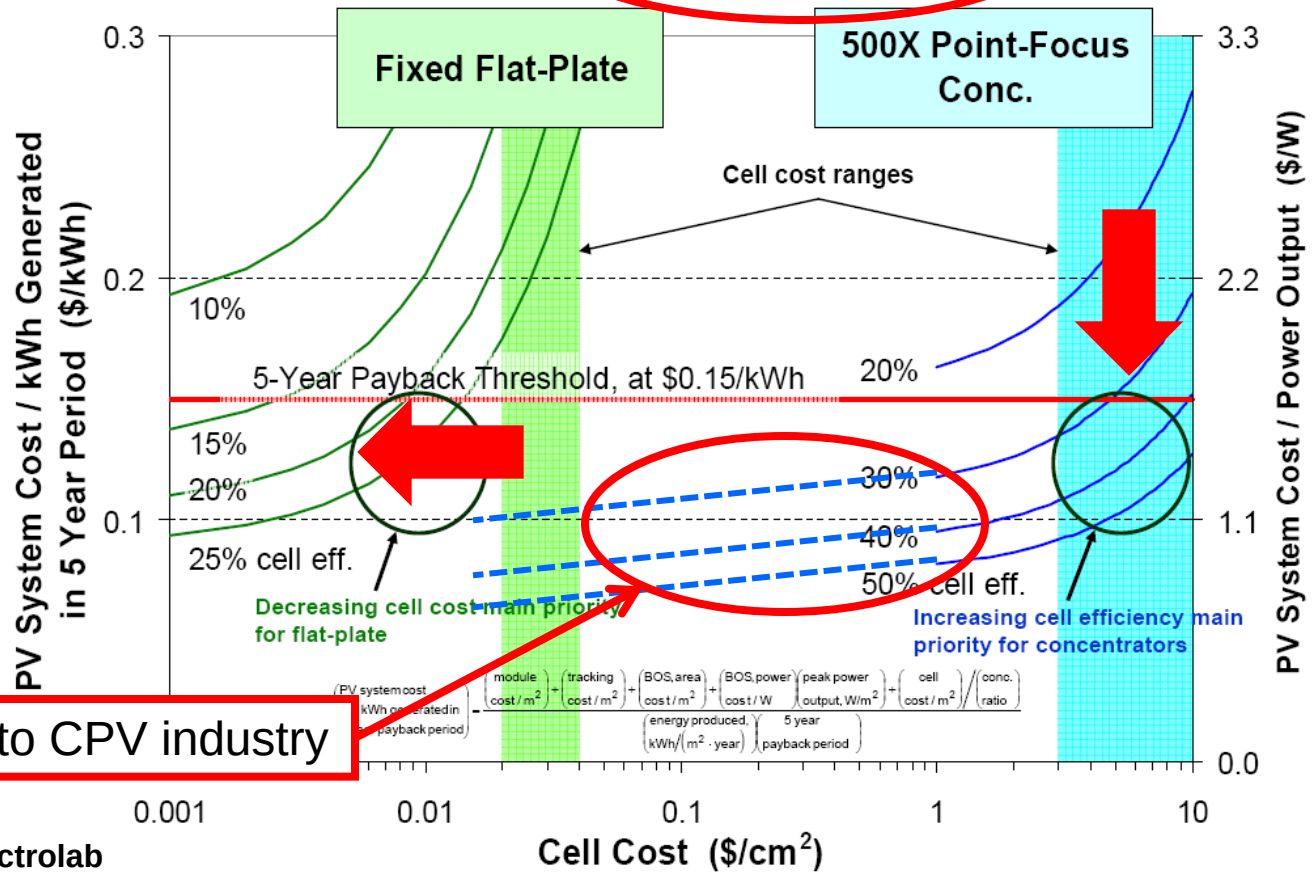
- Cell efficiency, magnification, cell cost ($/Cm2)



Huge value to CPV industry

Source: Boeing Spectrolab

Can the cost of CPV approach flat plate using Si wafers?

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Rare earth oxides (REOs)…

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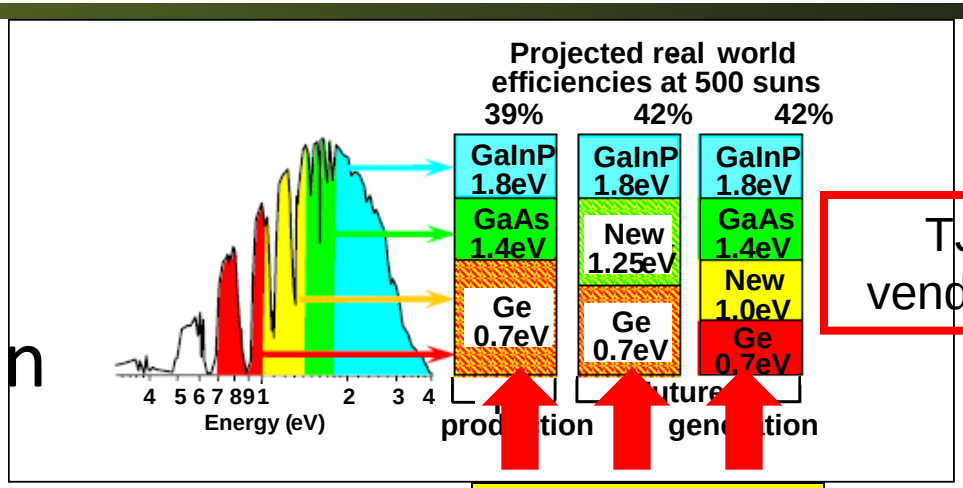
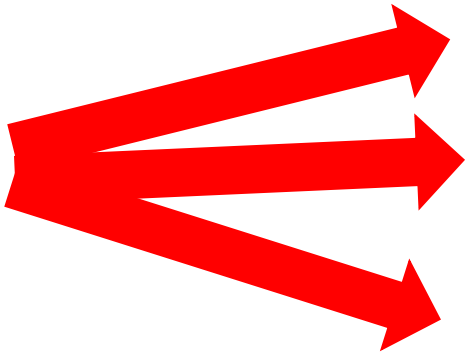
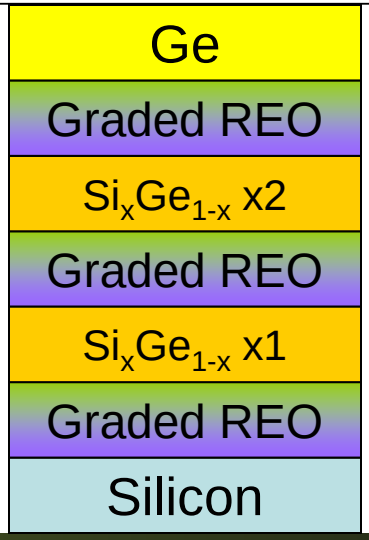
- Use silicon wafer
- Grow REO then Ge
- Grow Triple Junction



- Rare earth oxide





The race to provide low $ substrates has begun…

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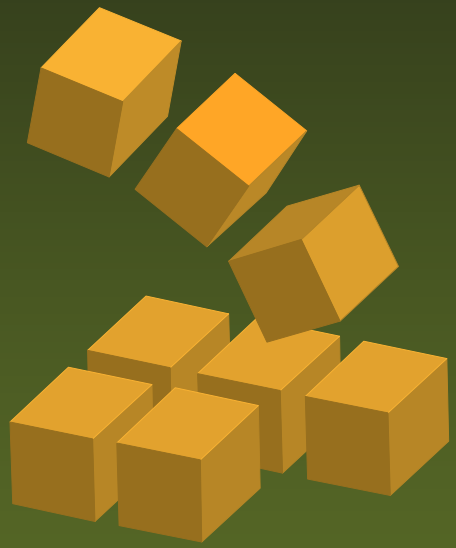

Rare earth oxides…

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1st exciting moment at TLI…

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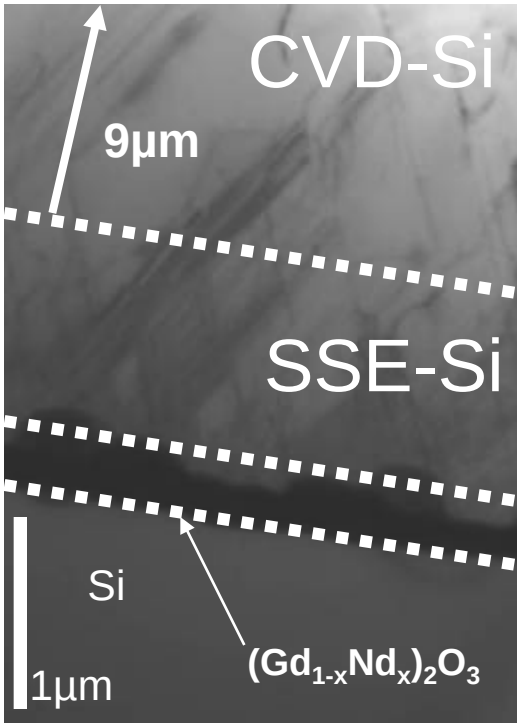
- Wafers currently support industry standard Si-CVD techniques
- Up to 10 µm of good quality CVD silicon grown on Translucent wafers



10 µm silicon by ASM Epsilon CVD using TCS (<111> Si)

Natural SOI technology…

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2nd exciting moment at TLI…

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- Using rare earth oxides to lattice match different materials…
  - Lattice parameter of REOs is closely matched to twice the lattice parameter of silicon.
  - This enables growth of single crystal REOs on silicon without interfacial layers.
  - REOs form thermally stable interfaces with silicon even at high temperatures
  - Moisture absorption studies indicate that REOs in single crystal form are NOT hydroscopic.

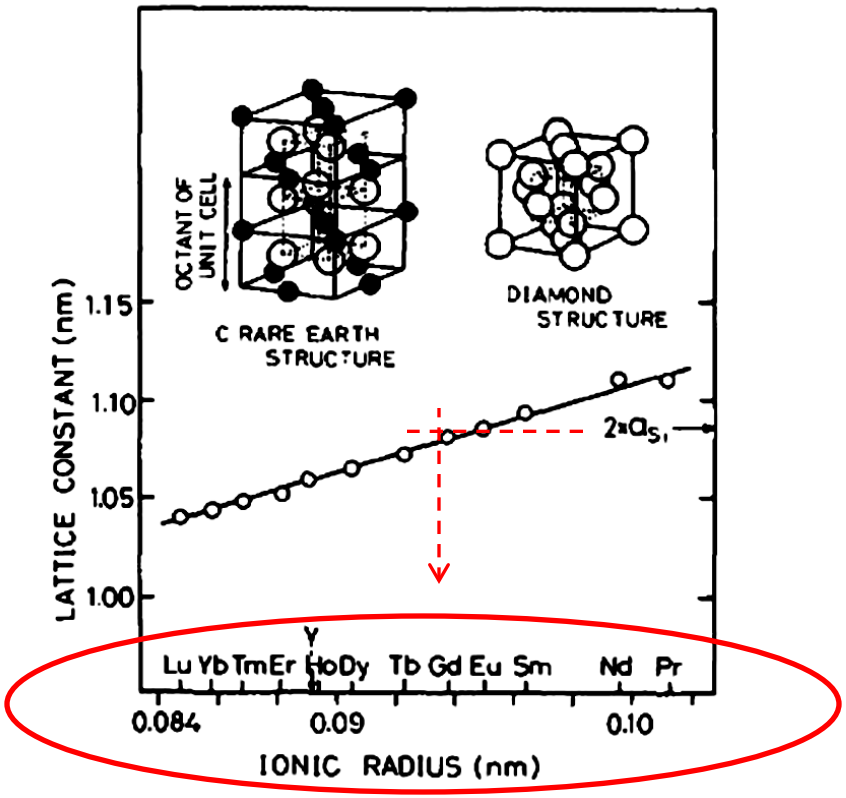

FIG. 1. Crystal structure and lattice constants of rare-earth sesquioxides.

Hitachi, J. App. Phys. 1987 Vol 61, #3, p 1030

RE as a compliant lattice match layer…

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Lattice parameter engineering

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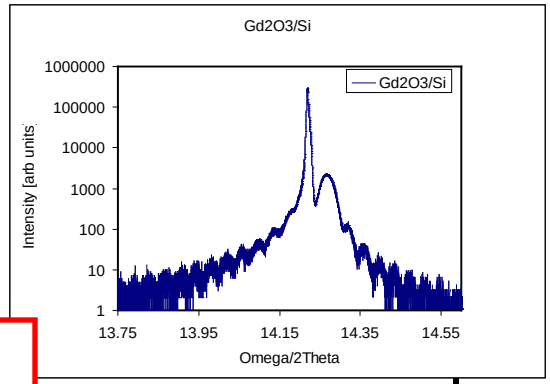
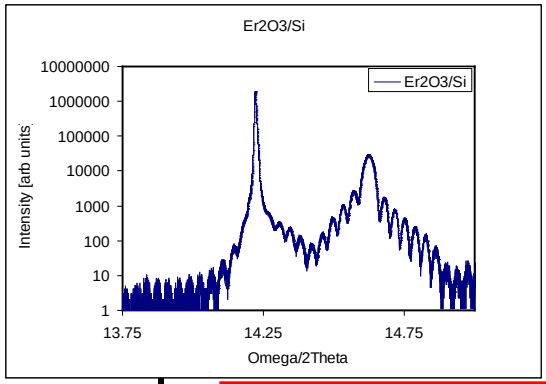
$2a_{Si}$ =10.86Å



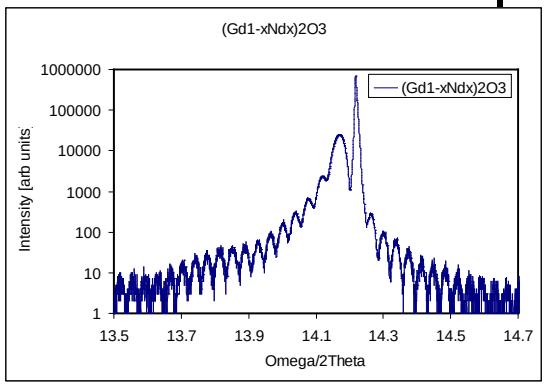


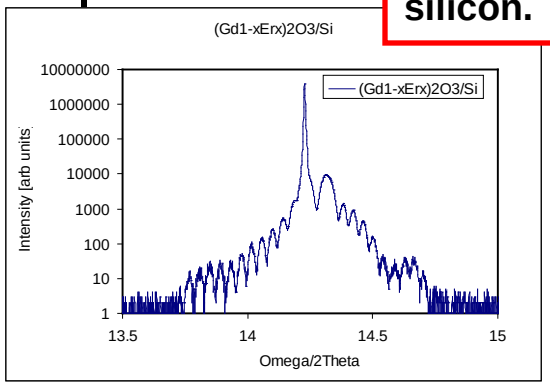
Rocking curves show lattice parameter engineering possible in this material system.

Formation of solid solutions enable flexibility in tuning the lattice parameter of the oxide to match that of silicon.

Nd_2O_3	Gd_2O_3	Er_2O_3
11.08Å	10.81Å	10.55Å

Si





High quality controllable material

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Natural epi vs bonded SOI

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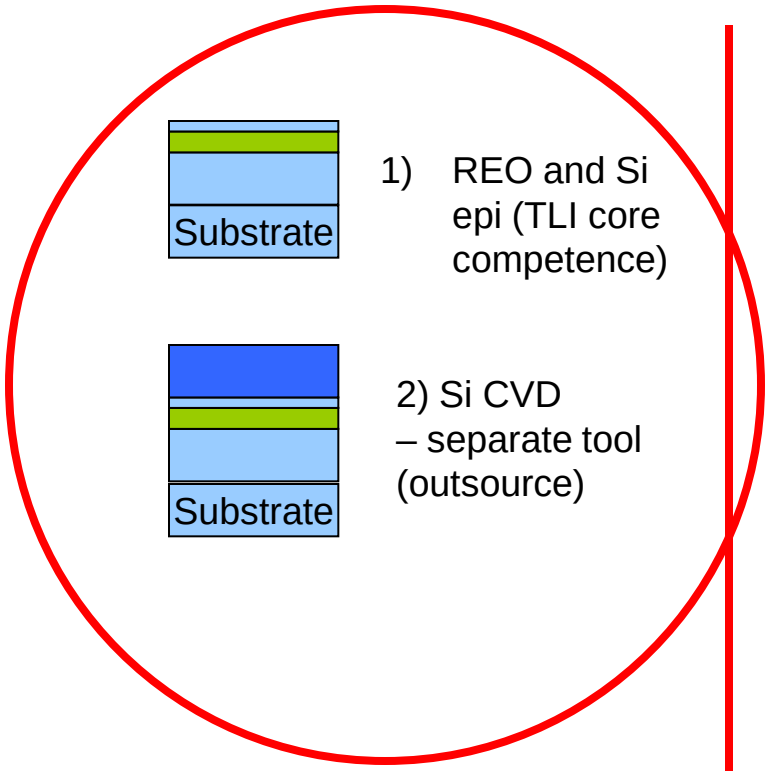
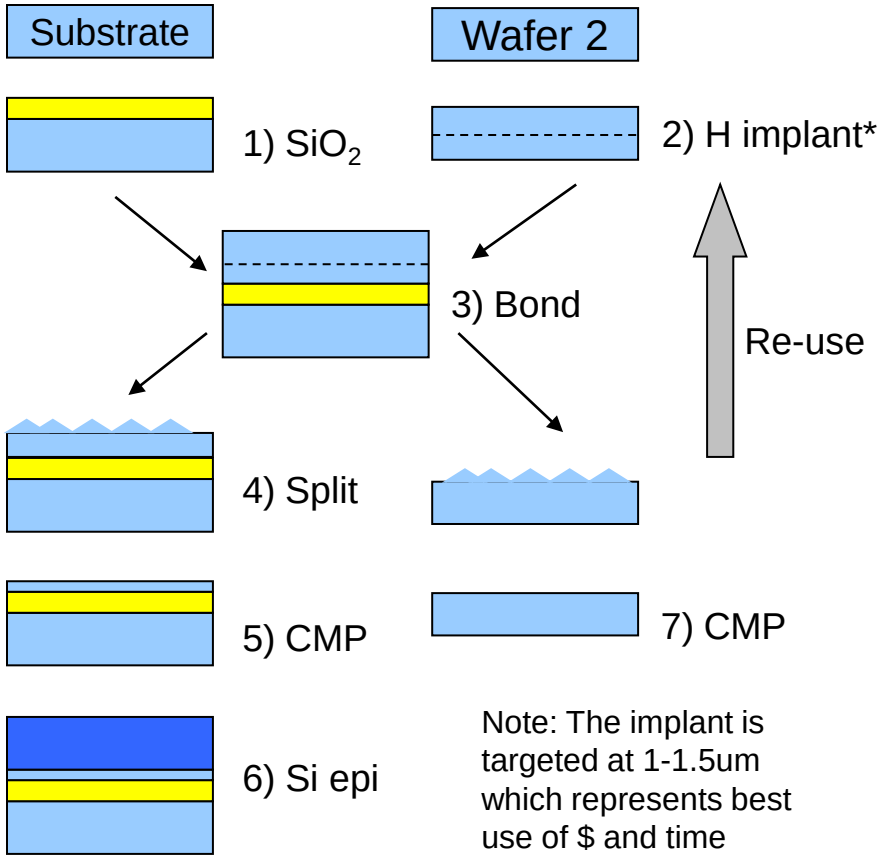


Translucent Crystal SOI™



Industry bonded wafers

Epitaxial solution is simpler & greener…(less $$$)

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Use in LEDs & photonics devices

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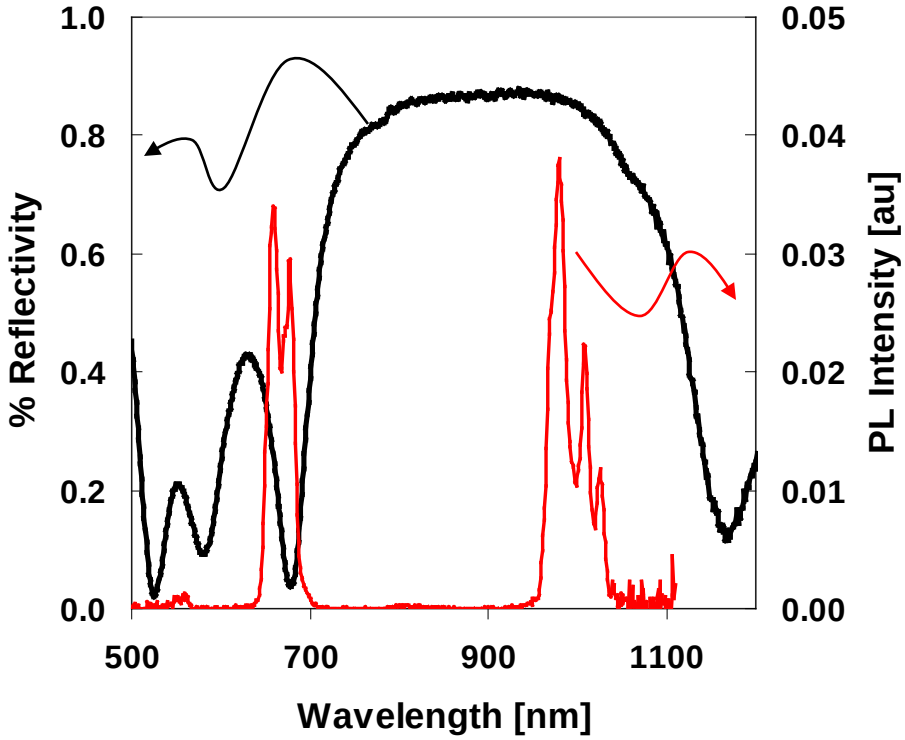

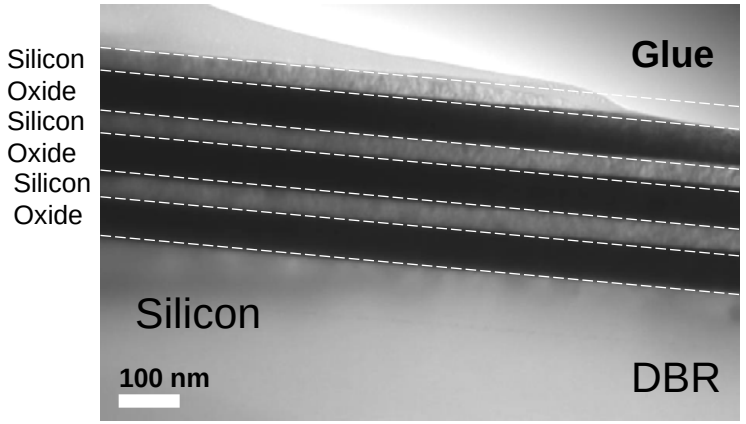

Distributed Bragg Reflector

- **Growth of high reflectivity distributed bragg reflectors in only 3 periods due to large Δn between REO (n=1.9) and silicon (n=3.65).**
- **DBR features ~90% reflectivity and a wide stop band of 200 nm.**
- **Oxide layer also exhibits photoluminescence from Er.**

High reflectivity epitaxial DBR to improve perf

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Harvesting the solar spectrum

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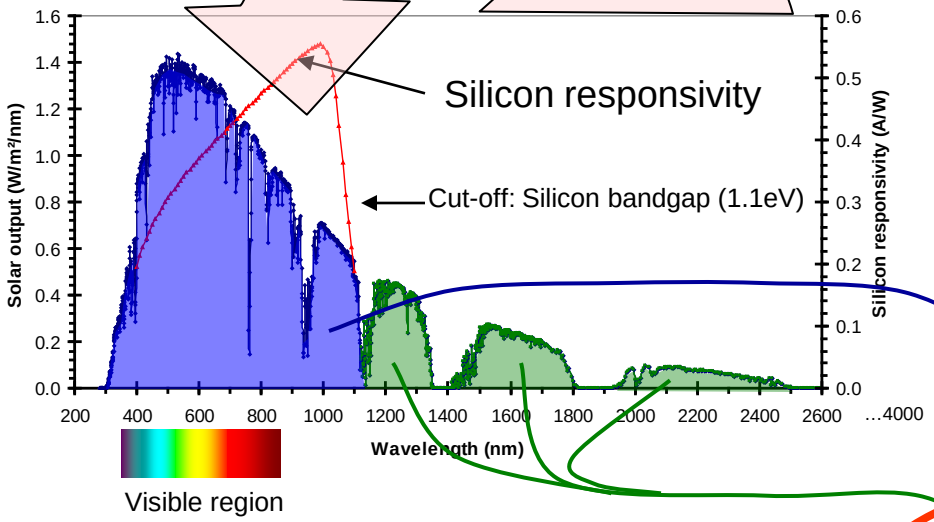

Integrating, to get the area under the graph:

λ=4000 nm
$\int_{\lambda=0\ nm}$ Solar spectrum . dλ = 900.27 W/m² **100.0%**

Total power density from the sun

λ=1120 nm
$\int_{\lambda=0\ nm}$ Solar spectrum . dλ = 716.76 W/m² **79.6%**

Power density up to the silicon bandgap

λ=4000 nm
$\int_{\lambda=1120\ nm}$ Solar spectrum . dλ = 183.51 W/m² **20.4%**

Power density beyond the silicon bandgap

20% of the available power from the sun remains unharvested using a silicon pn junction alone.

Solar spectrum:
ASTM G173-03 Reference Spectra Derived from SMARTS v. 2.9.2
Source: http://rredc.nrel.gov/solar/spectra/am1.5/

Silicon detector:
Calibration curve for a silicon photodetector
(Newport 818-SL)

Can we make solar cells more efficient?

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In spite of net loss: up conversion observed…

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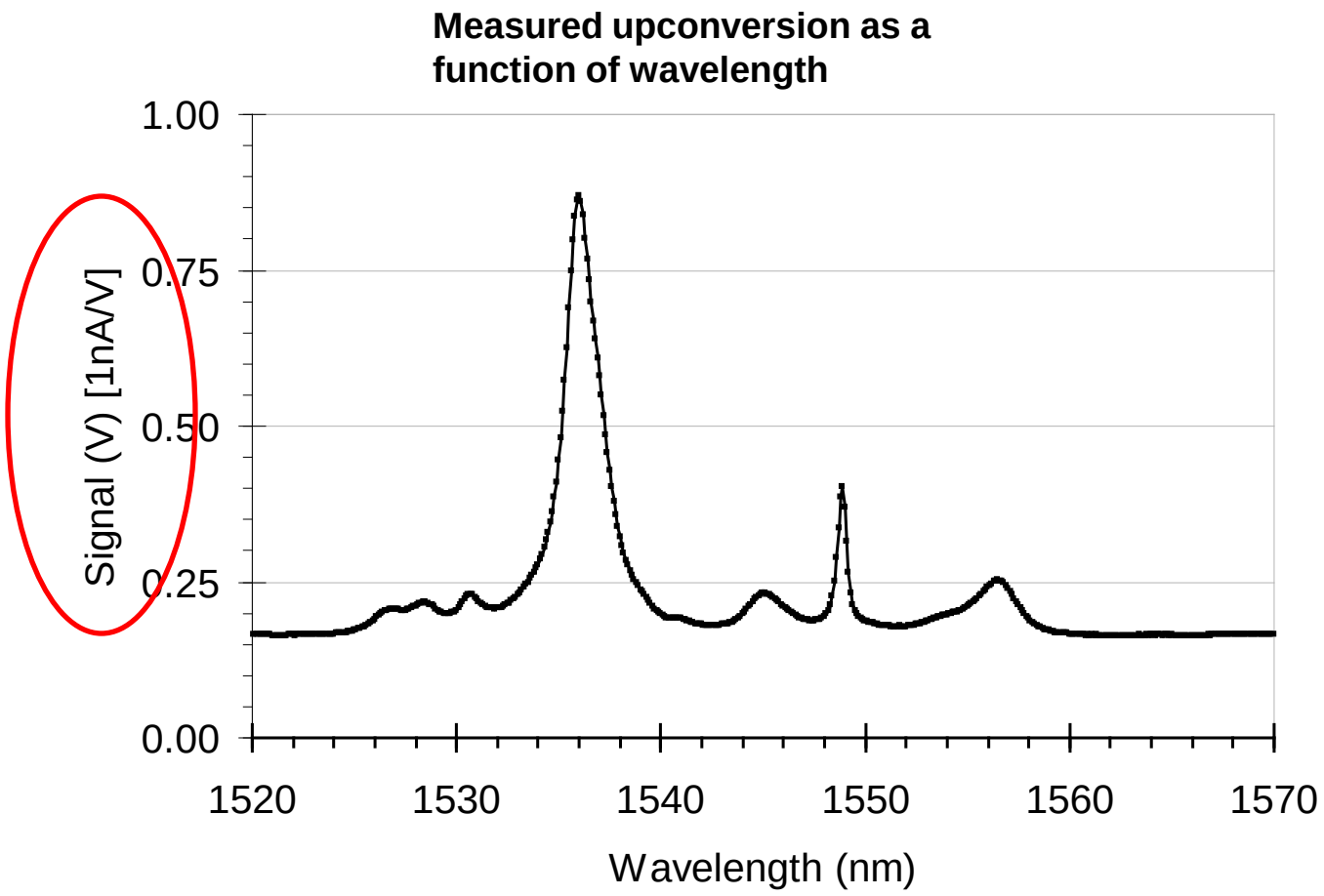

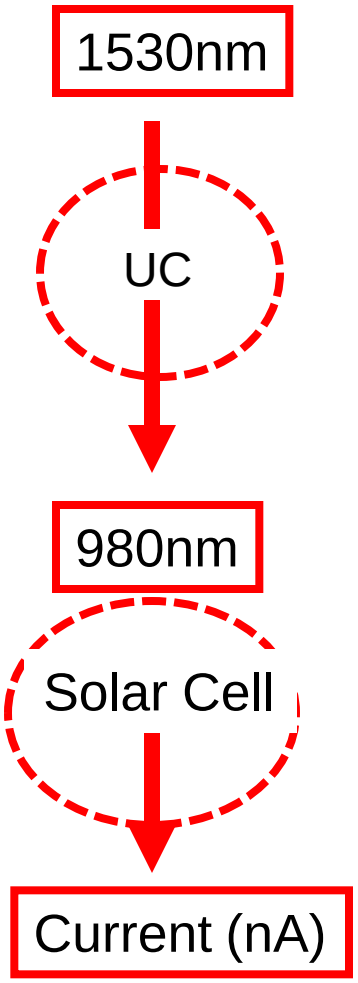

Challenge is to improve up-conversion of Er oxide

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3 key takeaways…

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- Photonics enables many things and is part of our lifestyle
- Photonics will be designed for many products and applications
- Photonics is green and will enable new technologies and products ***that will also be green…***

Lifestyle, photonics, green

lebby@translucentinc.com

End of presentation

Translucent Inc
Earth Abundant Materials Technology.

Michael Lebby, PhD MBA Deng CEng

General Manager & Chief Technology Officer
lebby@translucentinc.com

Translucent

Earth Abundant Materials Technology

Translucent Inc
952 Commercial St
Palo Alto, CA94303

Thank you for listening

Silex Systems Subsidiaries

Translucent Inc
Earth Abundant Materials Technology.

Founded: 1988
IPO: 1998 (SLX.AX)

Silex Systems Limited

Translucent Inc
Advanced materials

Chronologic
Instrumentation

SilexSolar
PV panel business
(formerly BP Solar Sydney Olympic Park)

Solar Systems
Utility scale PV

Advanced green technologies

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Translucent Inc: History

Translucent Inc
Earth Abundant Materials Technology.

2001 Company founded by a postdoc from Prof. David A.B. Miller's group at Stanford University. Translucent was focussed on the development of Erbium Doped Waveguide Amplifiers (EDWAs) for the Telecommunications Industry. Investors included Silex Systems.

2003 Silex takes a majority ownership of Translucent Inc.

2004 Translucent files first SOI related patents.

2006 Translucent focuses on technologies for the solar energy industry.

2010 Michael Lebby brought in as General Manager. SOI and Ge-on-silicon is identified as key strategic directions for the company.

2011 SOI and solar solutions

952 Commercial St. Palo Alto, CA94303

Decade of materials R&D with rare earth oxides…

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Silicon photonics

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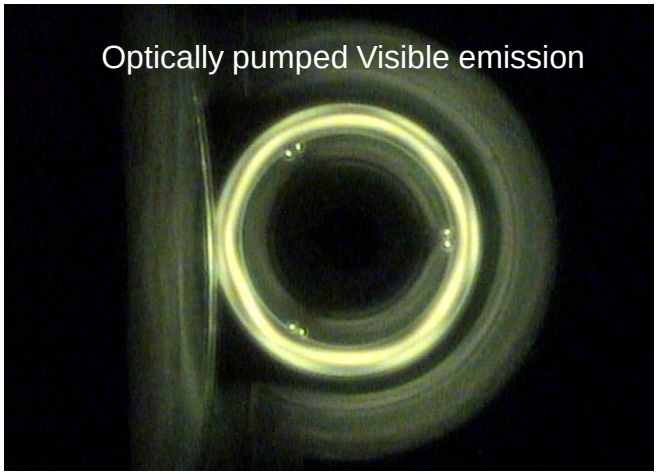
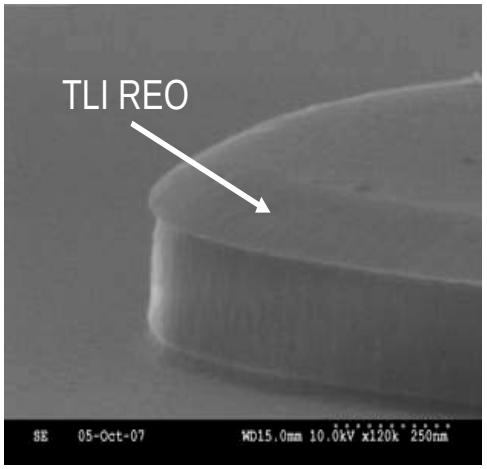
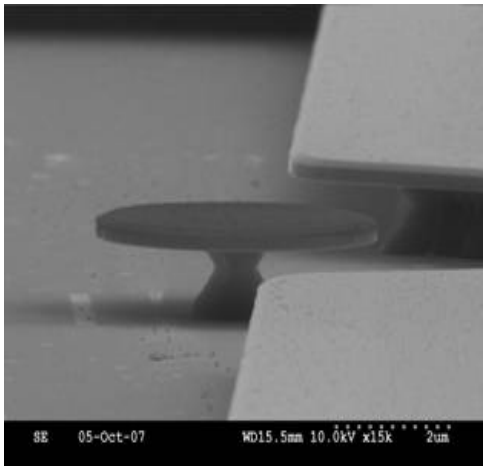
REO Photonics with DARPA

Translucent Inc
Earth Abundant Materials Technology.

- Partner with Caltech in phase I and phase II of DARPA – EPIC program







Source – Caltech 2008 DARPA-EPIC report

Optically stimulation → need electrical for product

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Impact of green display manufacturing

Translucent Inc

Earth Abundant Materials Technology.

Element	Improvement in Product or Process	Impact
Light Efficiency Improvement	Backlight efficiency, Pixel transmittance	50 % reduction in power consumption
Backlight	Low Hg lamp, Fewer backlight lamps	30-50 % reduction in Hg content
Glass, printed circuit board, liquid crystal material, integrated circuits, sealing materials, etc.	Green component selection	Eliminate arsenic from glass, Eliminate halogens, Eliminate brominated fire retardant
Water consumption	Low water processing	Reduce water consumption per glass area by 70%
Greenhouse gas	Low emission processes	Reduce green house gas emissions per glass area by 70%
Shipping packaging material	Redesign shipping packaging	Save 21,000 trees, 48,000 tons water, 3,000 MWhr electricity, 2,000 ton CO_2
Shipping transportation	Maximize shipping contained loading	Save 6,300 ton CO_2 , 13,000 MWhr electricity
Waste production	Recycle glass, Reuse solvents, Reduce sludge, Reuse sludge	80 % waste recovery rate

Source: AU Optronics

Improving processes across the board

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