



Computing & Sustainability

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We've all seen the figures

- ◆ Climate change
- ◆ Exhaustion of mineral resources
- ◆ Overpopulation
- ◆ Deforestation
- ◆ Mass extinctions
- ◆ Loss of fresh water
- ◆ . . .



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In the next 100 years we'll...

- ◆ Destroy the mountains of Appalachia

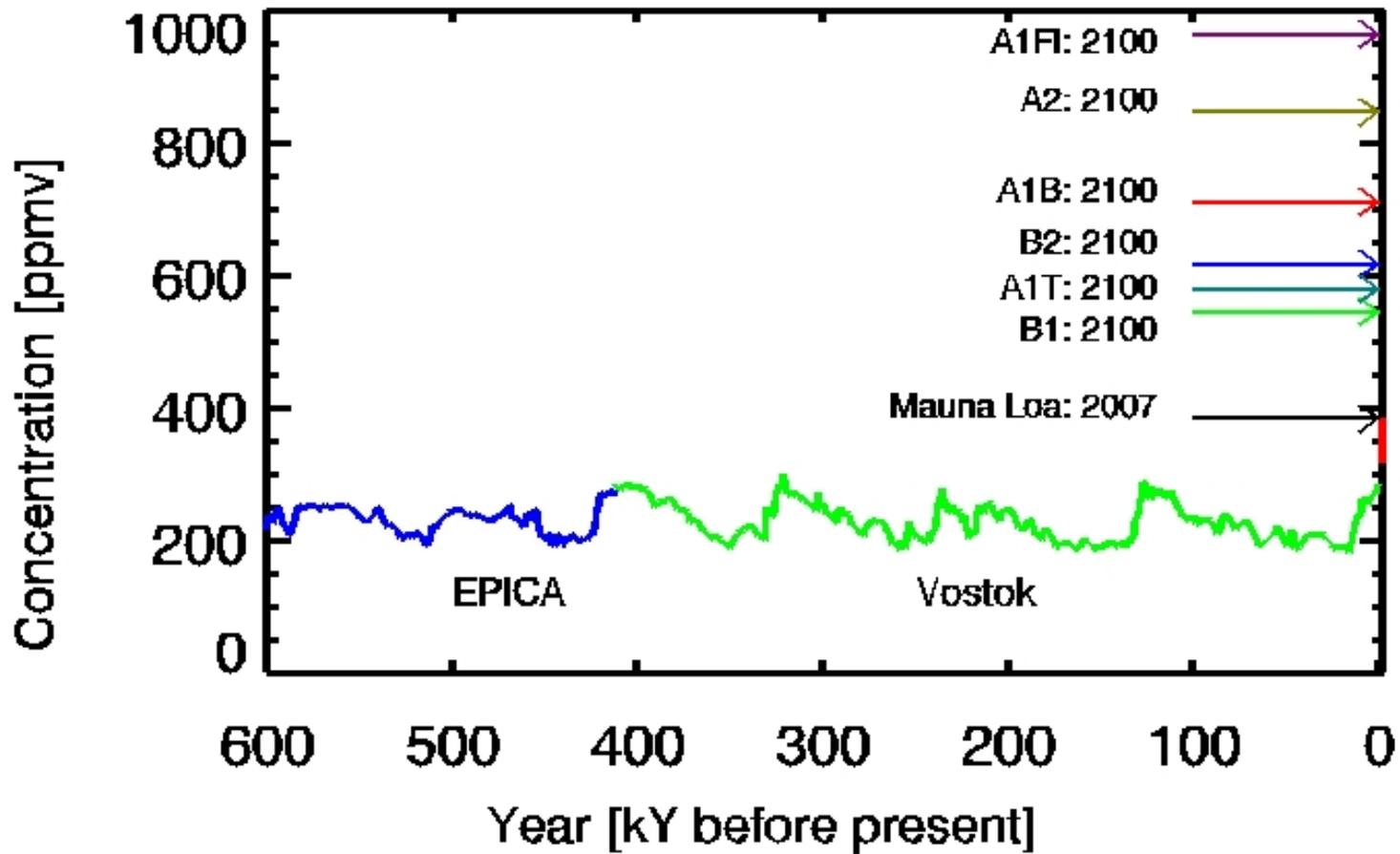
◆ and the boreal forests of Alberta



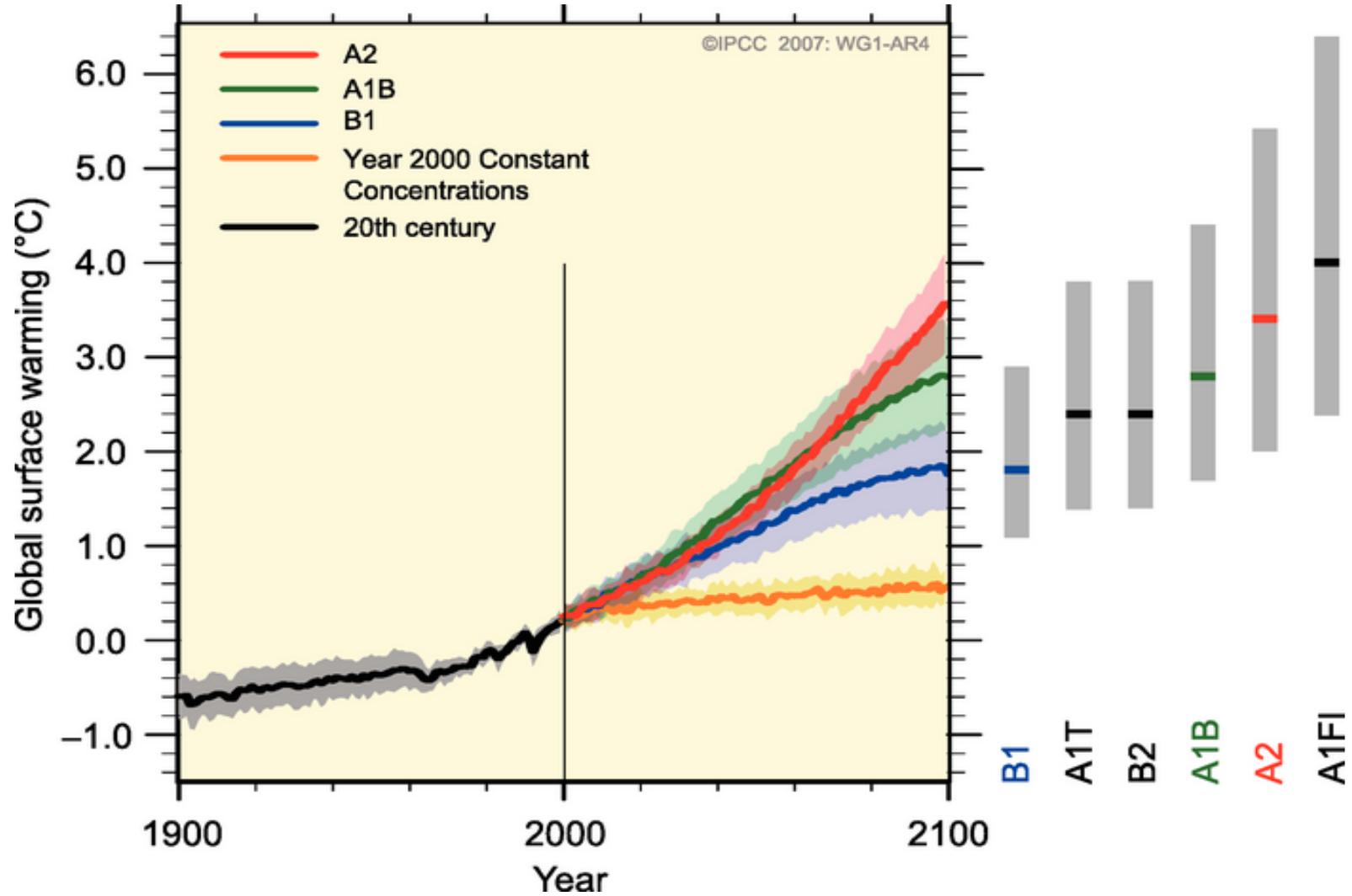
◆ and the equatorial rain forests



CO₂



Temperature



Sea Level Rise

- ◆ IPCC: .2-.6m by 2100, absent ice sheet melting
- ◆ Up to 6 or 7m if Greenland melts
- ◆ Up to 60m from Antarctica
- ◆ (Probably not by 2100, but who says history stops then?)

- ◆ At some point the statistics get personal...





So...

- » I'm motivated
- » I'm also a computer scientist
- » It seemed like I ought to put the two together—
hence this talk

◆ Note that:

- » I'm not an expert on climate change
- » I'm not even an expert on the impact on computers
on the environment
- » There is way too much to cover in an hour

Outline

- ◆ Computer manufacturing and disposal
- ◆ Operational costs
- ◆ Positive impacts from
 - » dematerialization
 - » monitoring & assessment
 - » system integration
 - » optimization
 - » modeling
 - » control/ problem solving

e-Waste

- ◆ Several billion electronic devices in the US
 - » 300M cell phones alone
- ◆ 400M devices discarded every year
 - » 3M tons in 2008
 - » accounts for 70% of the heavy metals in US landfills
- ◆ Only about 15% recycled, 2/3 of that abroad



Guiyu, China

- ◆ Largest single site for electronics recycling
 - » 1.5M tons/yr
- ◆ Water too toxic to drink
- ◆ 82% of children have blood lead $>100\mu\text{g}/\text{dl}$
 - » AAP defines lead poisoning as $>10\mu\text{g}/\text{dl}$
 - » Research at Strong suggests that level is too high



Toxic Menu

- ◆ Lead (solder, batteries, CRTs)
- ◆ Beryllium (copper alloy)
- ◆ Cadmium (batteries, CRTs)
- ◆ Mercury (fluorescent backlights, batteries)
- ◆ Brominated flame retardants (plastic)
- ◆ PVC (insulation—releases dioxin when burned)
- ◆ Phthalates
- ◆ ...

Toxic Procurement

- ◆ Gold, copper
- ◆ Rare earths (15 lanthanides + Sc & Y)
 - » NiMH batteries
(lanthanum—10kg in a Prius)
 - » optical polishing and doping (cerium)
 - » ceramics, phosphors, lasers, ...
 - » permanent magnets (neodymium, gadolinium, others)
 - » Not especially toxic (or rare), but the mining *is*
 - low concentration ores
 - high in radioactive thorium, uranium



Mountain Pass, CA

- ◆ Once the principal worldwide source of rare earths
- ◆ Long history of environmental problems
- ◆ Closed in 2002
- ◆ Supply now comes from China



Legal Framework

- ◆ EU RoHS & WEEE Directives [2003]
 - » bans lead, cadmium, mercury, hexavalent chromium, brominated fire retardants at levels above 0.1%
 - has impacted the market worldwide
 - » makes manufacturers responsible for recycling
- ◆ Basel Convention [1992]
 - » regulates trade in hazardous waste
 - » US has never ratified
- ◆ “Basel Ban”
 - » prohibits export from developed to developing world
 - » status in dispute

Possible Remediation

- ◆ Reduce, reuse, recycle (safely!)
- ◆ Design for easy disassembly
- ◆ Switch to less wasteful/toxic technologies
 - » flat screens, LED backlights
 - » lead-free solder
- ◆ Increased regulation
 - » internalization of costs (ala WEEE; cf. bottle deposits)
 - » ratify Basel Convention, Ban

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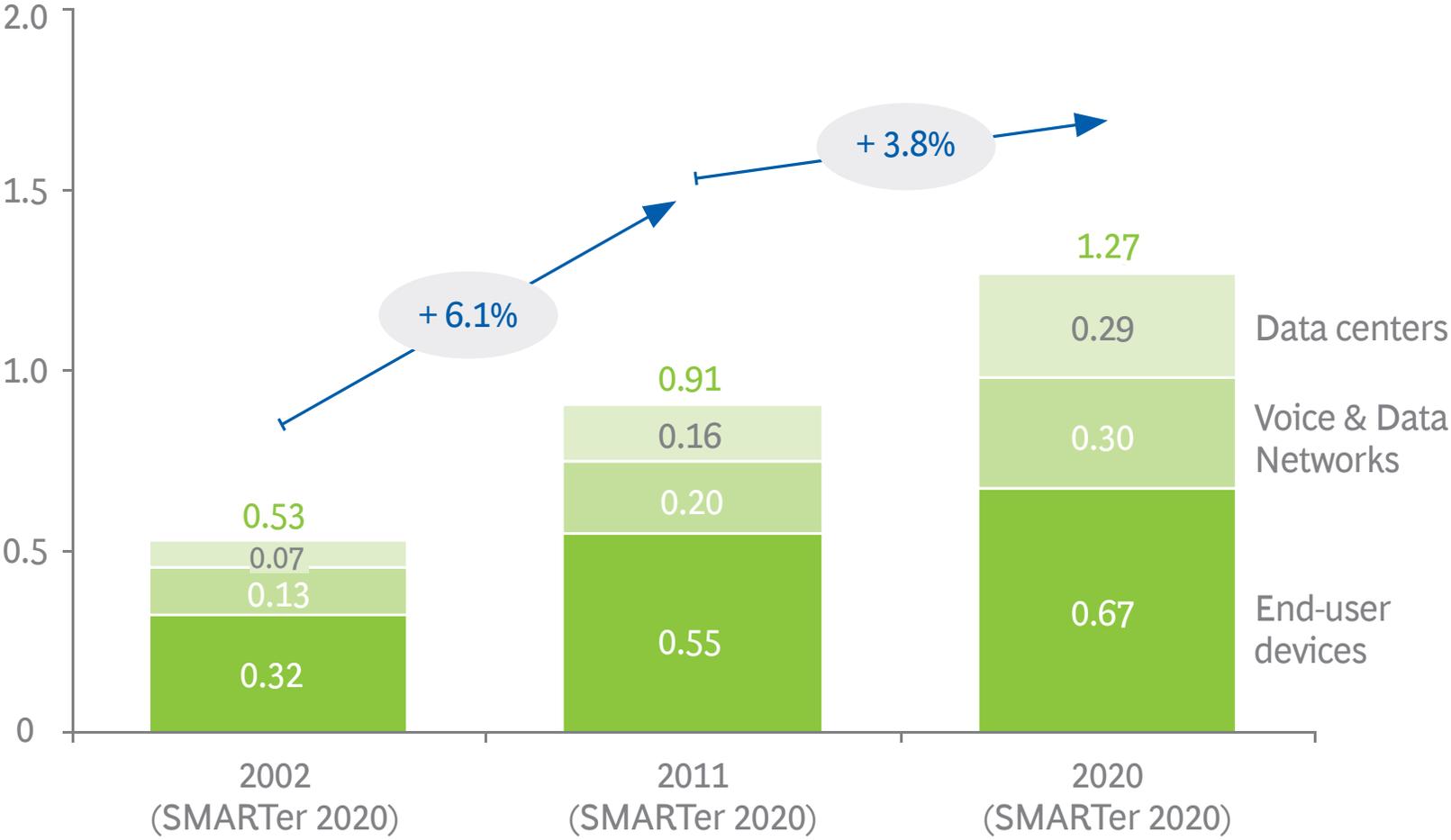
Projections

	2002	2020 BAU	2050 BAU
World output	40 GtCO ₂ e	55 GtCO ₂ e	80 GtCO ₂ e
IEA/Stern target for climate stabilization		20 Gt	
IT sector	0.5 Gt	1.3 Gt	
% of carbon footprint	1.3 %	2.3 %	
% world GDP	5.8 %	8.7 %	
GeSI potential abatement		9.1 Gt	
=		16.5 % *	
or approximately the carbon footprint of Russia			

* more on this in a few minutes

IT Footprint Growth

Global ICT emissions (GtCO₂e)



ICT as percentage of global emissions

1.3

1.9

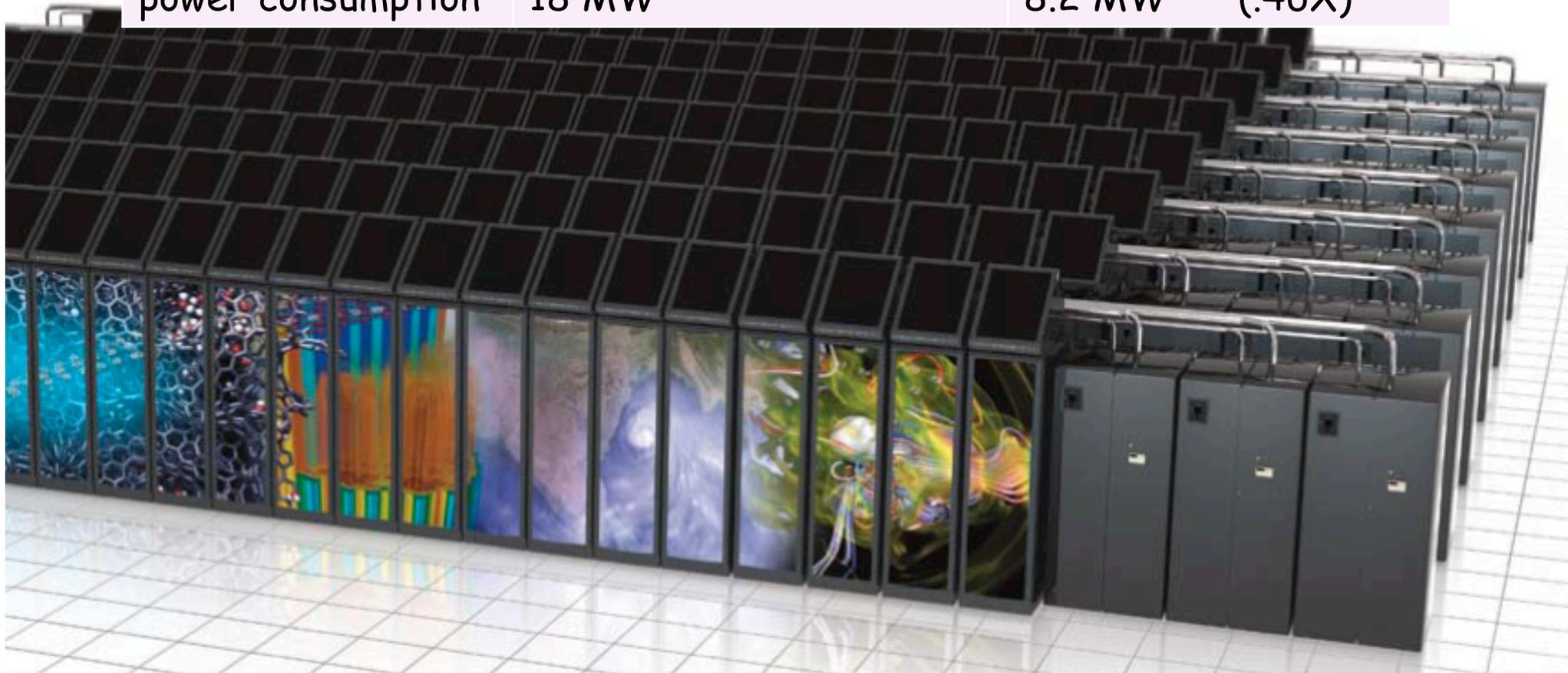
2.3

IT Energy Trends

- ◆ Instructions per joule doubling every 16 months since the 1940s
- ◆ But demand outpacing that → growing footprint
- ◆ Major qualitative changes
 - » desktops → laptops → phones
 - » CRTs → LCDs → LED backlights
 - » traditional data centers → “cloud”
 - » POTS landlines → broadband & mobile

World's Fastest Computer

	Earth Simulator (Japan)	Titan (ORNL)
completion date	2002	2012
cost	\$480M	\$60M (.125X)
speed	36 Tflop	17.6 Gflop (500X)
power consumption	18 MW	8.2 MW (.46X)



Data Center Energy

- ◆ Power Usage Effectiveness (PUE)
 - » ~2 in older centers
 - » Google claims <1.1 in new centers

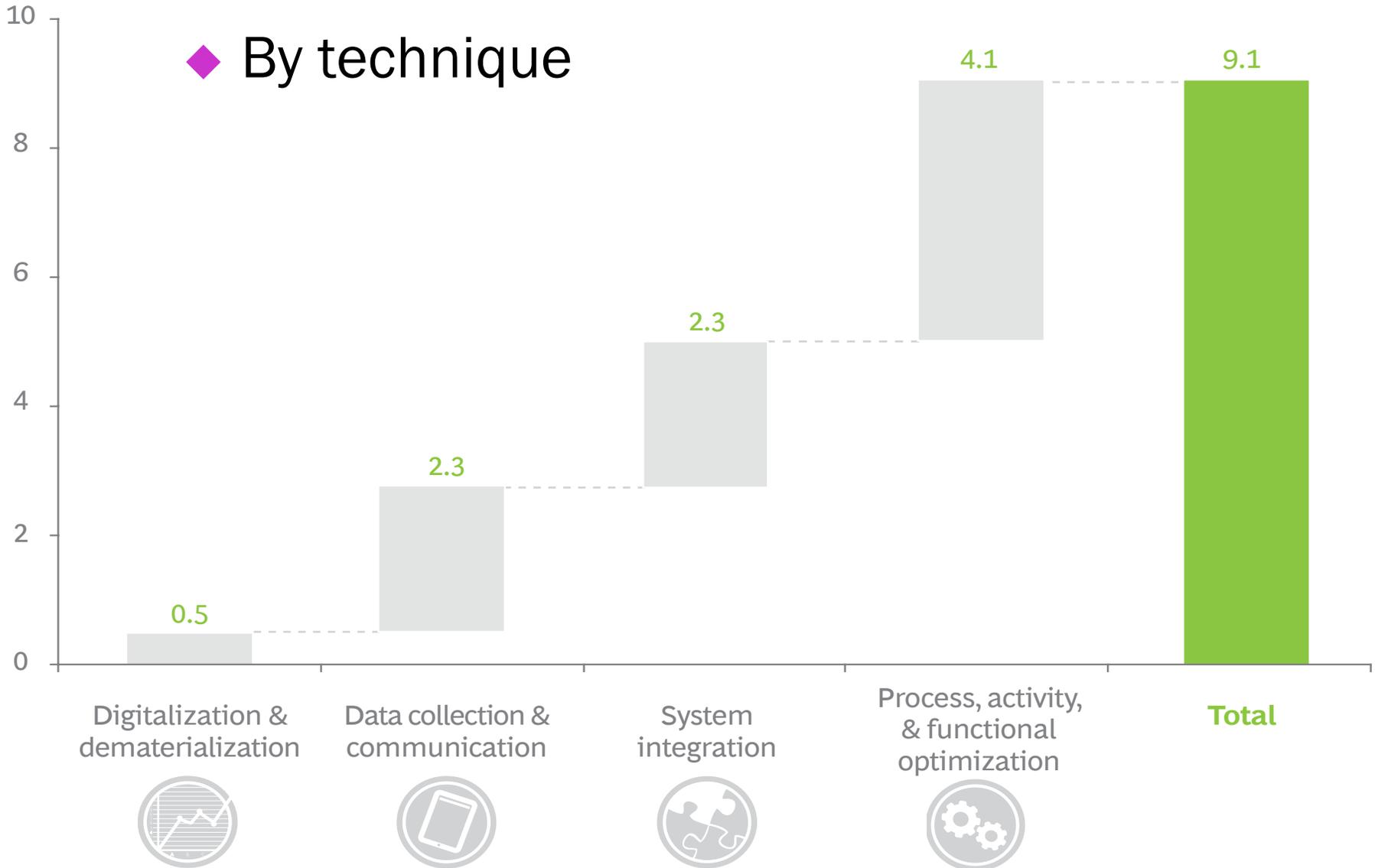
Hamina, Finland

Outline

- ◆ Computer manufacturing and disposal
 - ◆ Operational costs
 - ◆ **Positive impacts from**
 - » dematerialization
 - » monitoring & assessment
 - » system integration
 - » optimization
 - » modeling
 - » control/ problem solving
- } focus of GeSI report

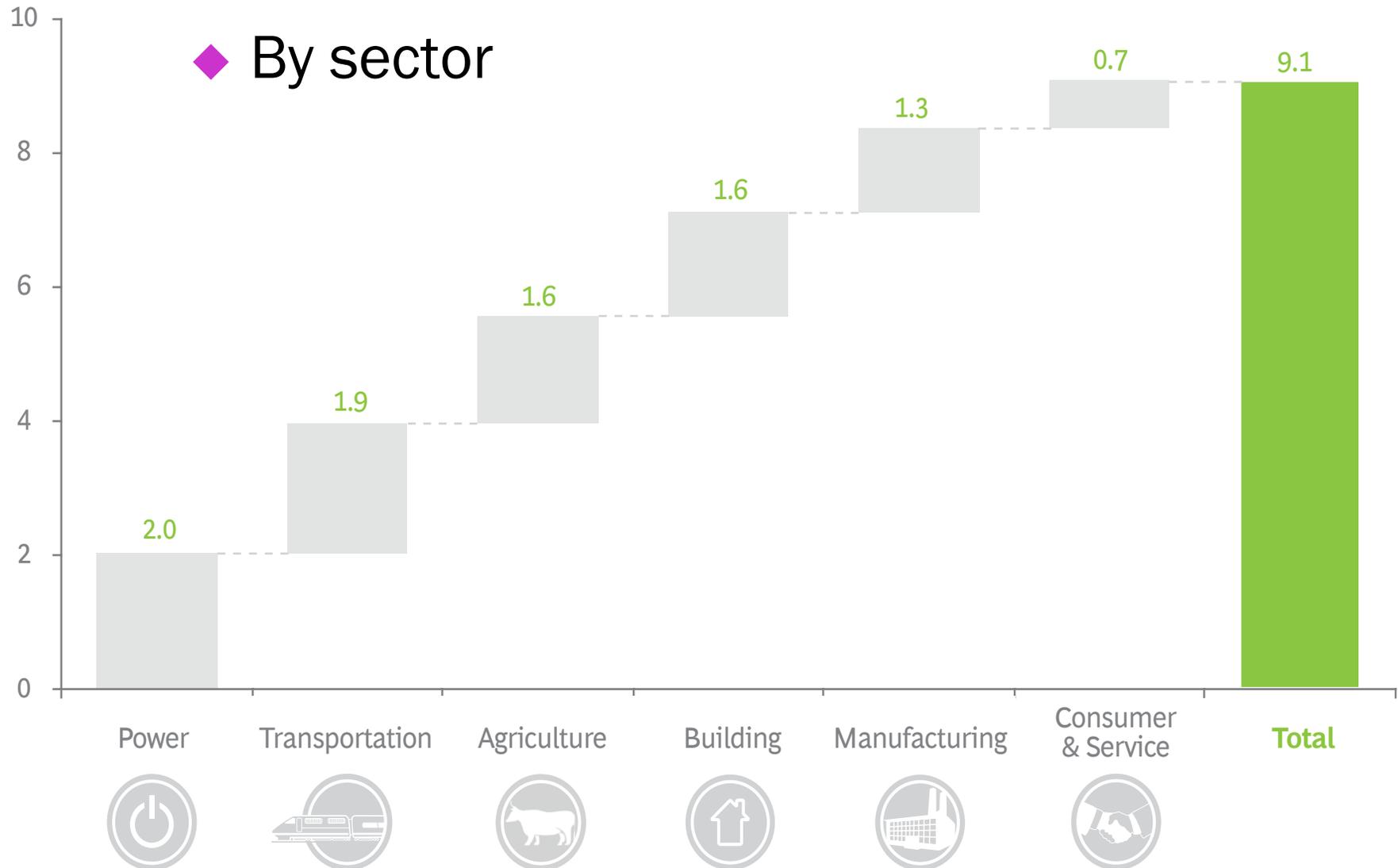
GeSI Abatement Estimates

Abatement potential (GtCO₂e)



GeSI Abatement Estimates

Abatement potential (GtCO₂e)



Examples (1)

- ◆ Dematerialization
 - » telecommuting, teleconferencing
 - » e-commerce
- ◆ Monitoring & assessment
 - » building audit
 - » eco-driving (routes, feedback)
- ◆ System integration
 - » building management
 - » renewables integration into power grid
- ◆ Optimization
 - » smart grid
 - » centralized distribution centers
 - » building design

Examples (2)

- ◆ Modeling
 - » climate, resource (e.g., water), fire modeling
 - » renewables R&D
 - » wildlife management
 - » pollution impact assessment
 - » carbon offset pricing
- ◆ Control / problem solving
 - » wind farm orientation to match the weather
 - » drive/fly by wire
 - » robotic intervention (e.g., to decommission reactors)
 - » stand-alone renewables management
 - » material/device development

Real world instance:

Corridor for grizzly bears in the Northern Rockies, connecting:

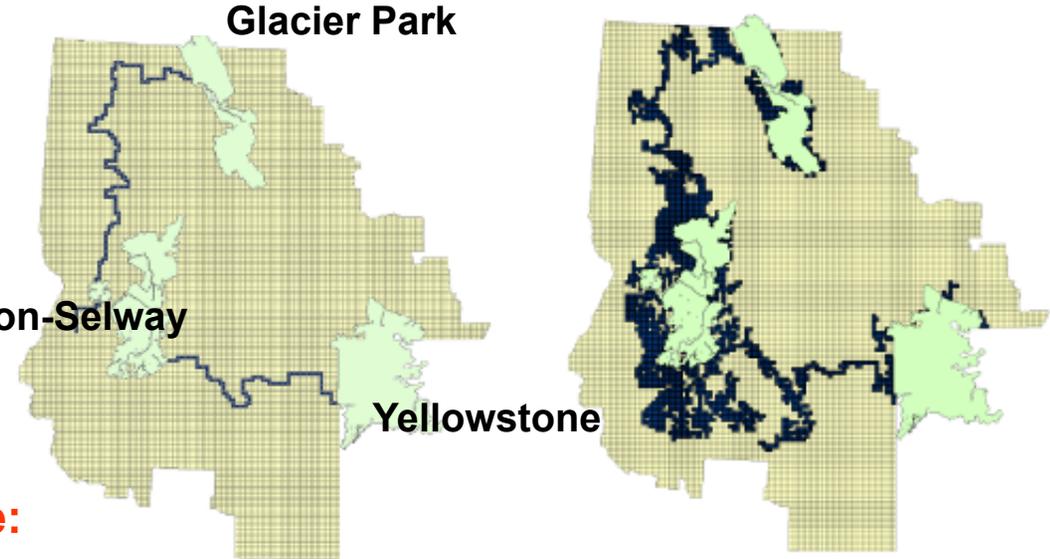
Yellowstone
Salmon-Selway Ecosystem
Glacier Park

(12788 nodes)



Salmon-Selway

Glacier Park



5 km grid
(12788 land parcels):
minimum cost solution

5 km grid
(12788 land parcels):
+1% of min. cost

Typical Case Analysis
Identification of Tractable Sub-problems
Streamlining for Optimization
Static/Dynamic Pruning

Our approach reduced corridor cost from **\$1 Billion to \$10 Million**
[Conrad et al. 2007]

Our Expedition is **partnering with the Conservation Fund** which works with US Fish & Wildlife Service and the Nature Conservancy on preserving habitat in the Northern Rockies .

Interdisciplinary Research Project (IRP):

Wildlife Corridors (Amundsen, Conrad, Gomes, Selman + postdoc + 2 Ph.D. students)



Spatio-temporal models from multiple sensors

The **Cornell** Lab
of Ornithology

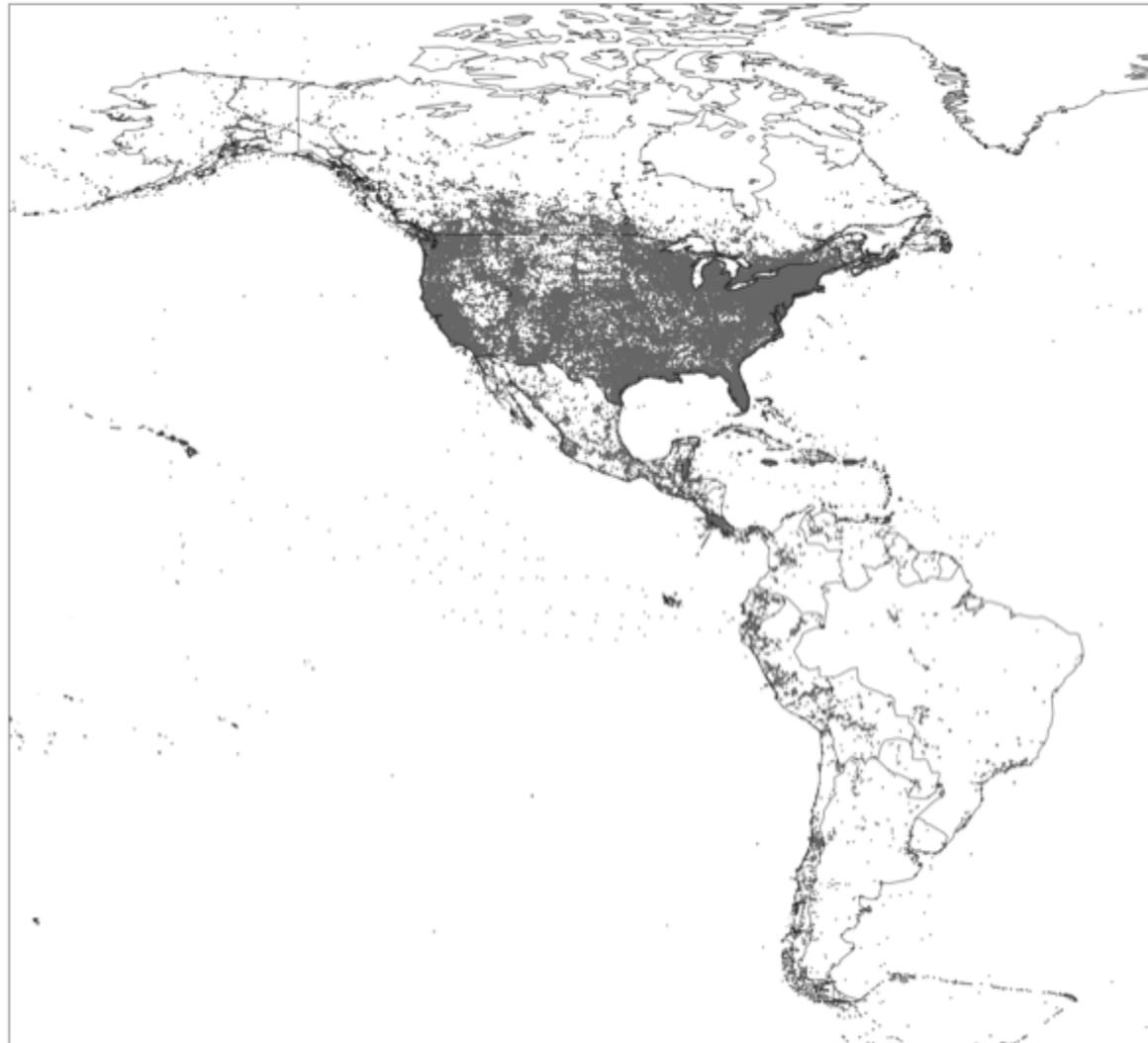
eBird

<http://www.ebird.org>

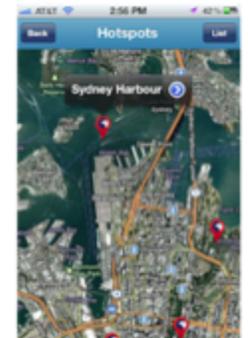
>100M Obs

>500K locs
(US)

~100K birders



Heterogeneous
Non-uniform
Dynamic

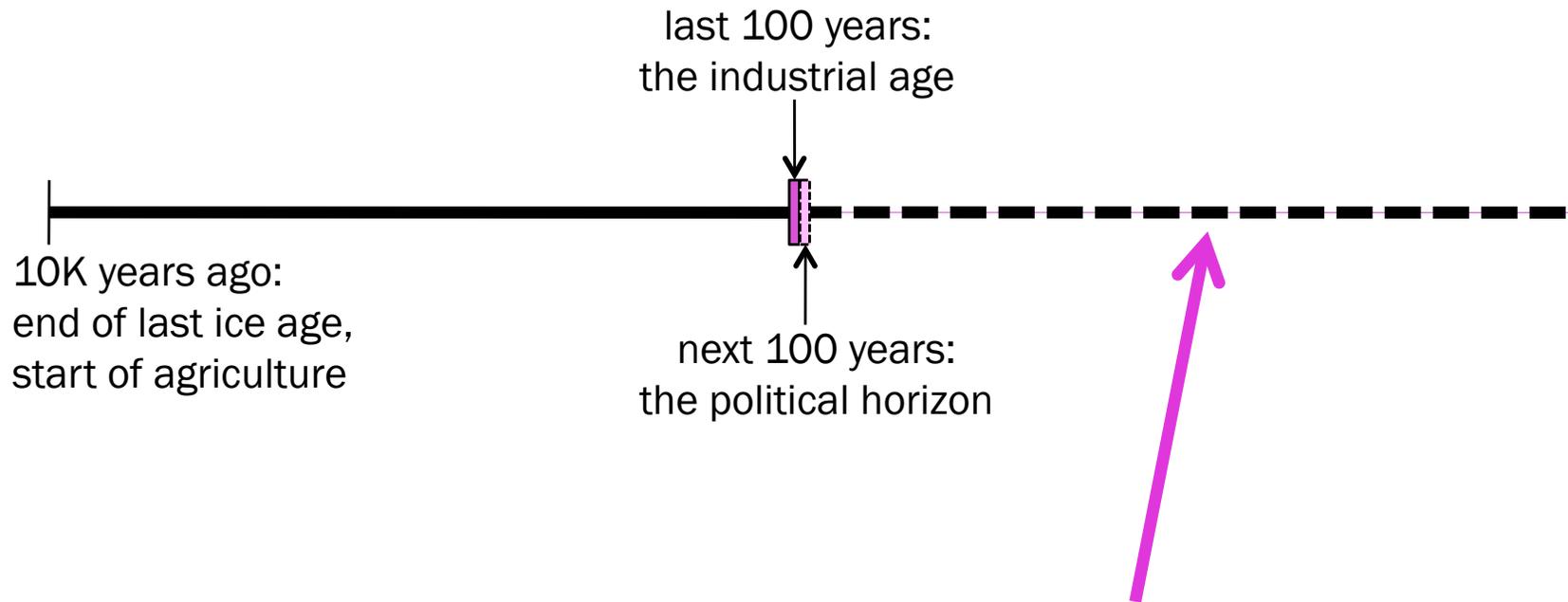




THE STATE OF THE BIRDS 2011
REPORT ON PUBLIC LANDS AND WATERS
United States of America

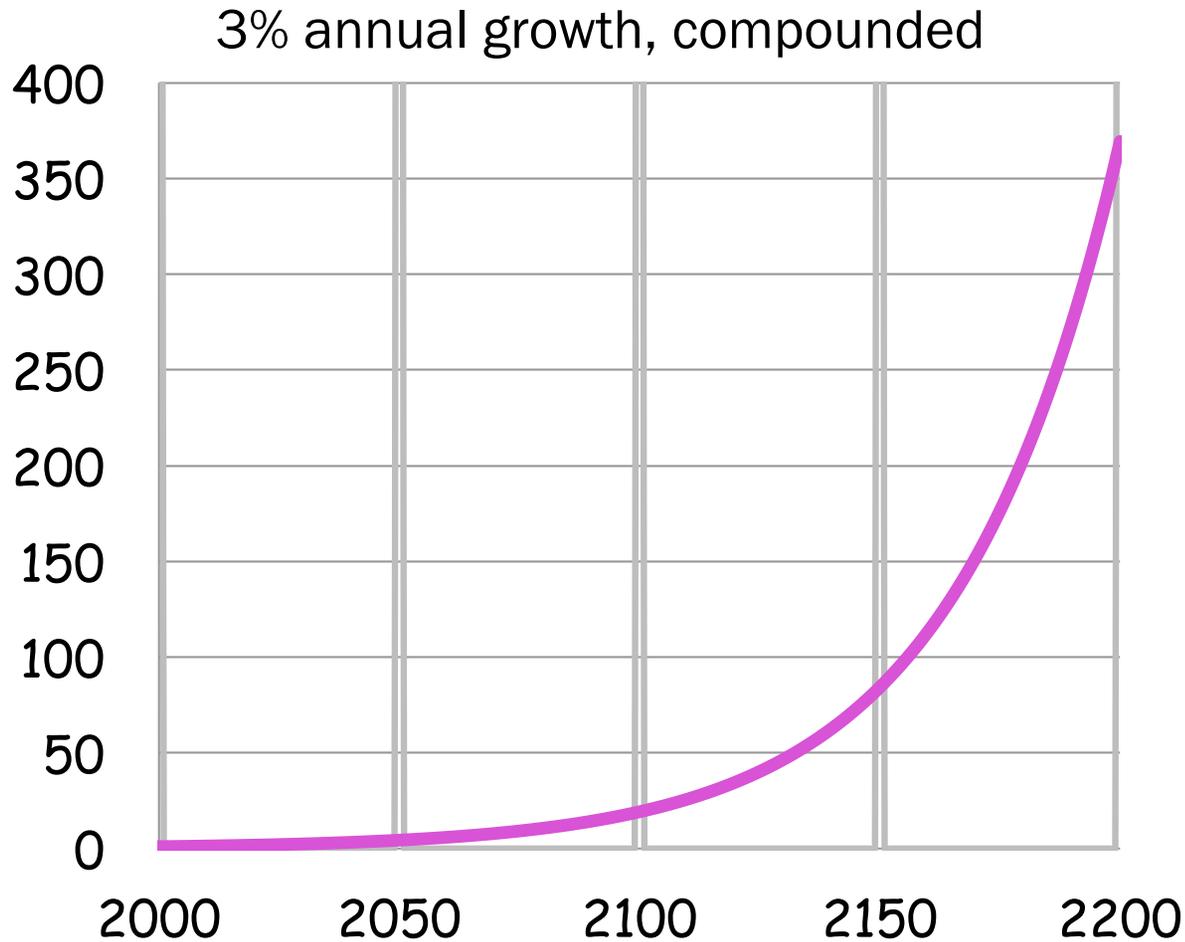


Longer Term



What about all of this?

Exponentials are relentless



◆ 370X as many

➤ cars

➤ jobs

➤ toasters

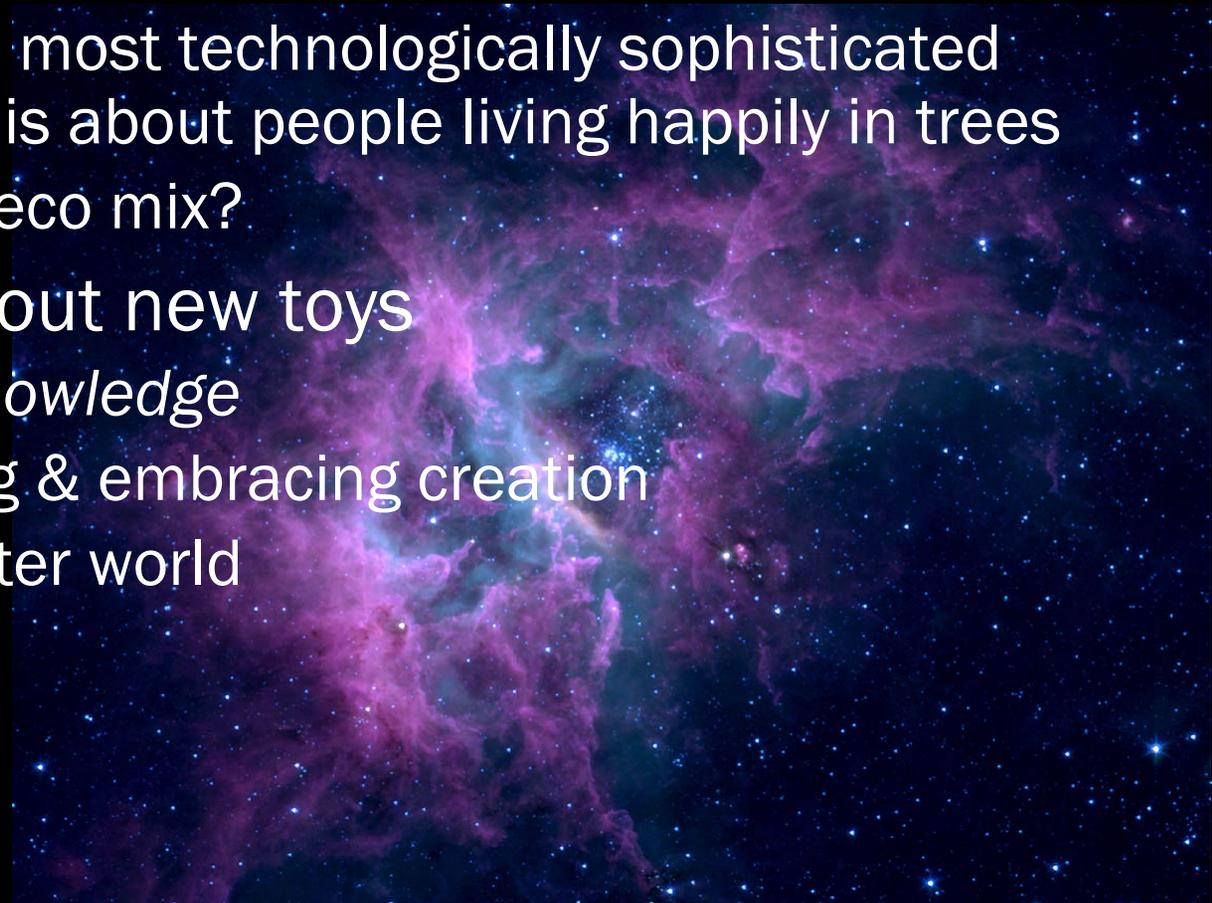
➤ ... ?

- ◆ How do we build a society that can endure for 10,000 years?
 - » one that doesn't consume *anything* non-renewable
- ◆ If we don't restore balance, Mother Nature will
 - » and we may not like her solution

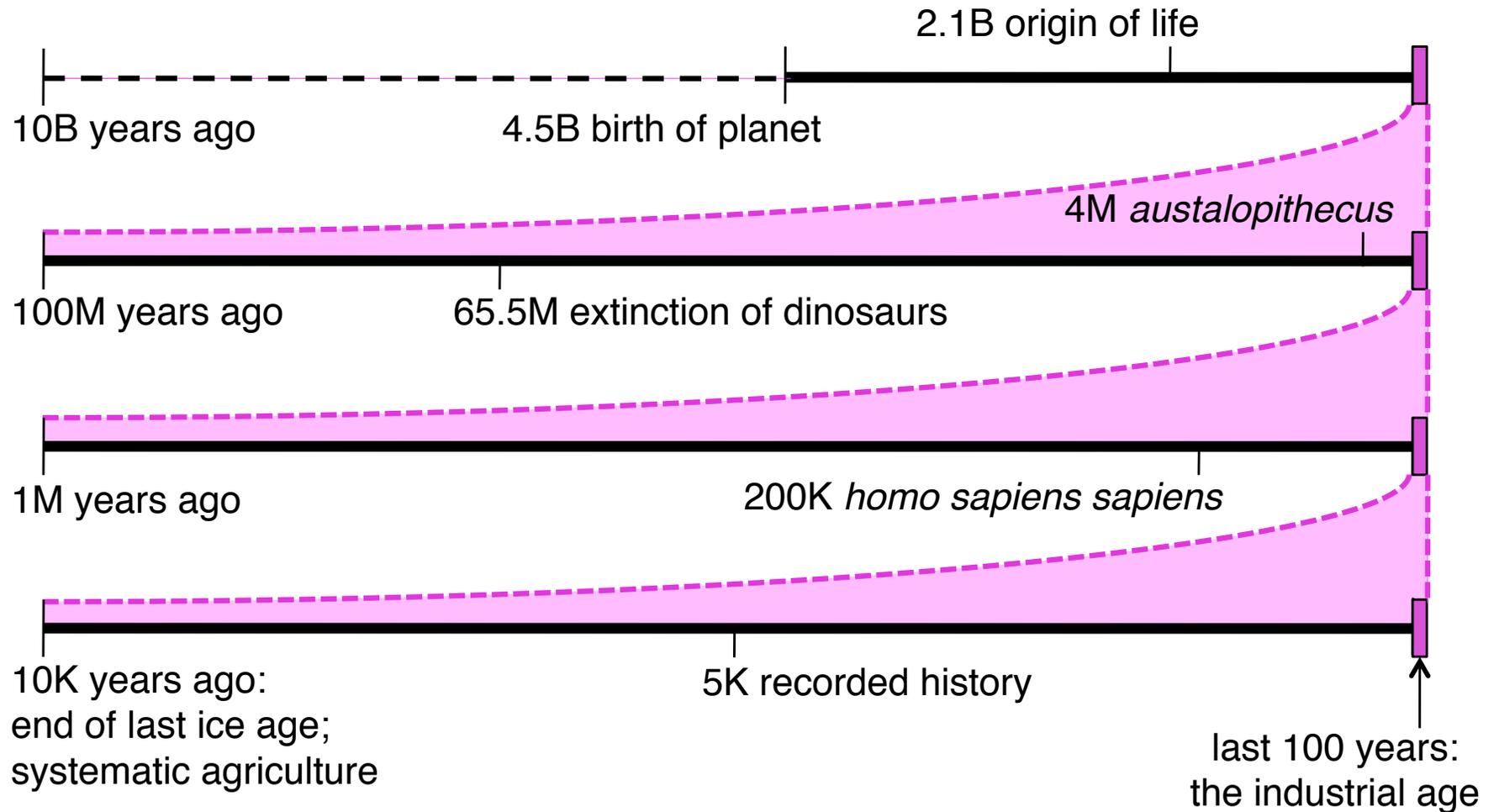


Visions of the future

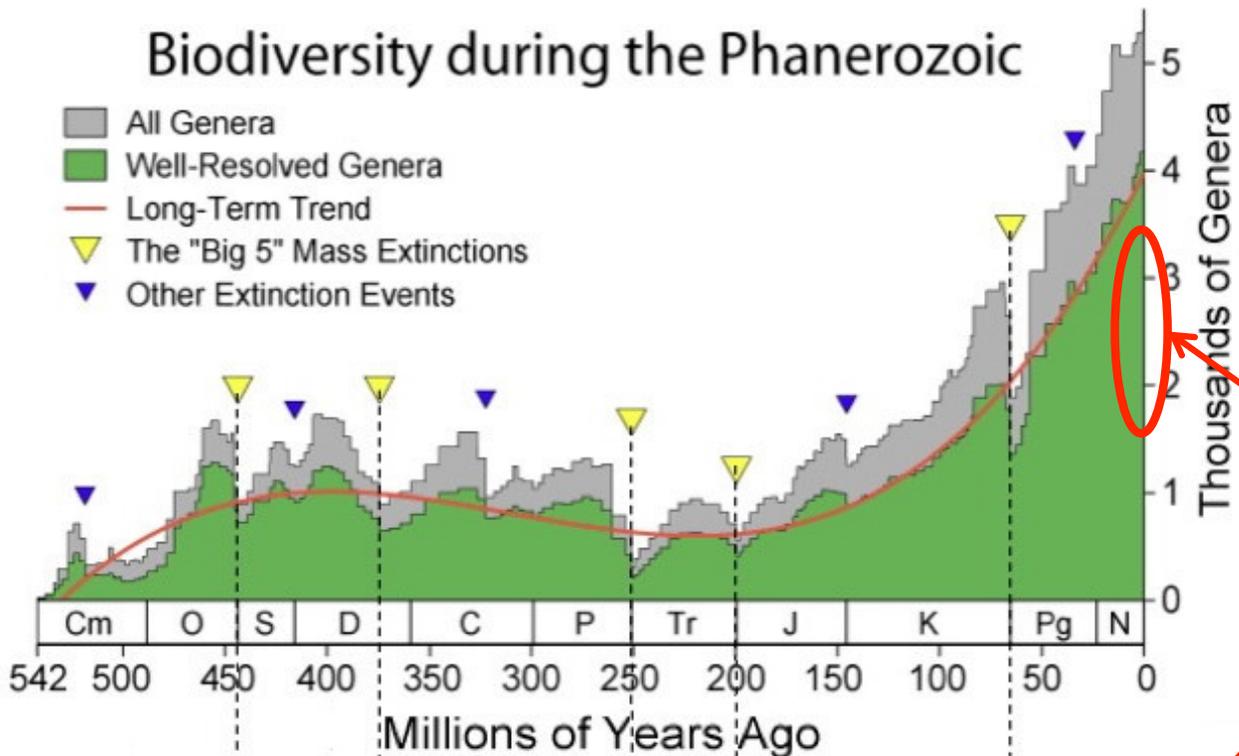
- ◆ Jim Gosling: do we want *Star Trek* or *Blade Runner*?
 - » or maybe *Avatar* ?
 - ironic that the most technologically sophisticated film in history is about people living happily in trees
 - » or some techno/eco mix?
- ◆ Science is not about new toys
 - » it's about new *knowledge*
 - understanding & embracing creation
 - building a better world



A little perspective



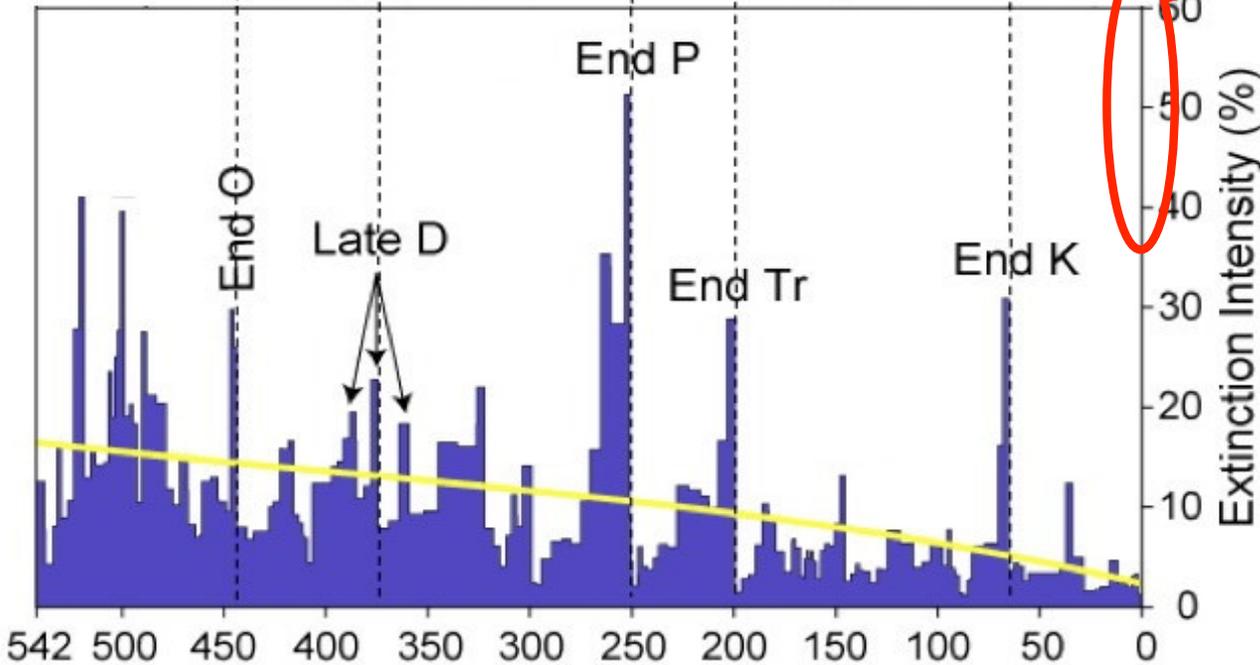
Biodiversity during the Phanerozoic



Biodiversity and extinction rates

We're looking (conservatively) at something in here

Extinction Intensity



- Cm** Cambrian
- O** Ordovician
- S** Silurian
- D** Devonian
- C** Carbonifer
- P** Permian
- Tr** Triassic
- J** Jurassic
- K** Cretaceous
- Pg** Paleogene
- N** Neocene

graphic: wikimedia commons