Technologies for Global Health

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Technologies for Global Health

Introduction & concepts

Examples of technologies for global health

- Pharmaceuticals
- Other technologies for global health

Discussion

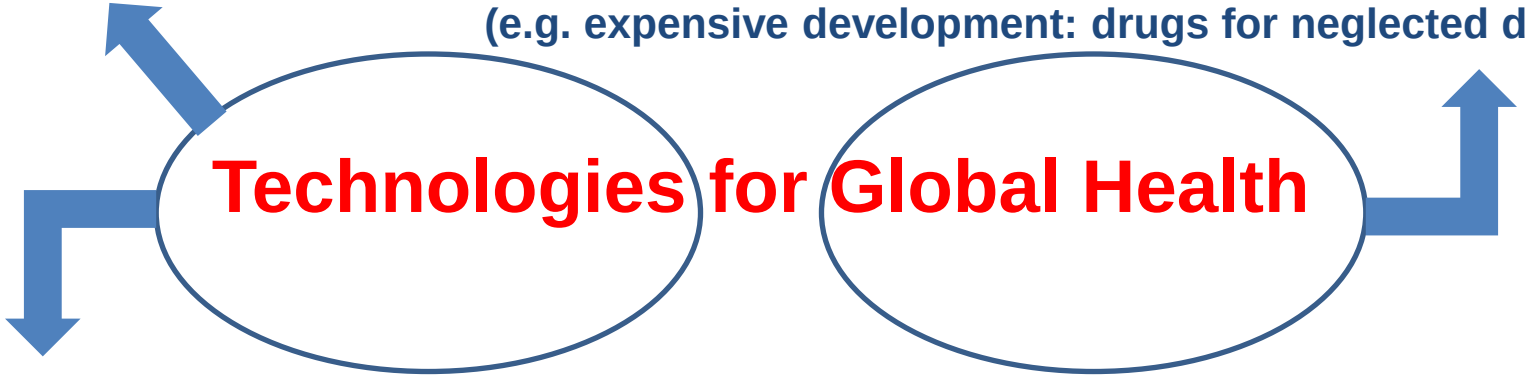
- General questions
- Global Health R&D Convention

‘Technology’ covers

- products **and** processes
- technological innovation **and** social innovation

‘Global health’: issues that

- transcend borders
  (e.g. pandemics; food safety)
- require collective, international effort
  (e.g. expensive development: drugs for neglected diseases



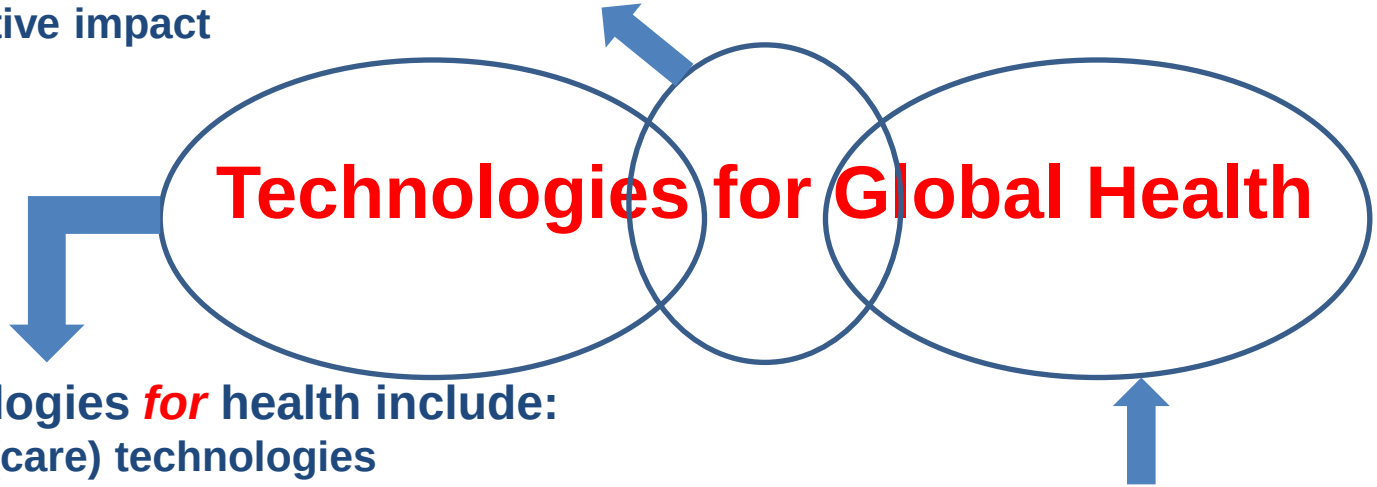
WHO: Health Technologies

The application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives.

http://apps.who.int/gb/ebwha/pdf_files/EB121/B121_11-en.pdf

‘Healthcare technologies’

- ***Health research -*** **research in biomedicine and health systems**
- ***Research for health -*** **research in any discipline or combination of disciplines to:**
  - **understand the impact on health of policies, programmes, processes, actions or events originating in any sector (Ottawa Charter 1986; 'Health in all policies' movement)**
  - **assist in developing interventions to help prevent or mitigate adverse impact /promote positive impact**



Technologies *for* health include:

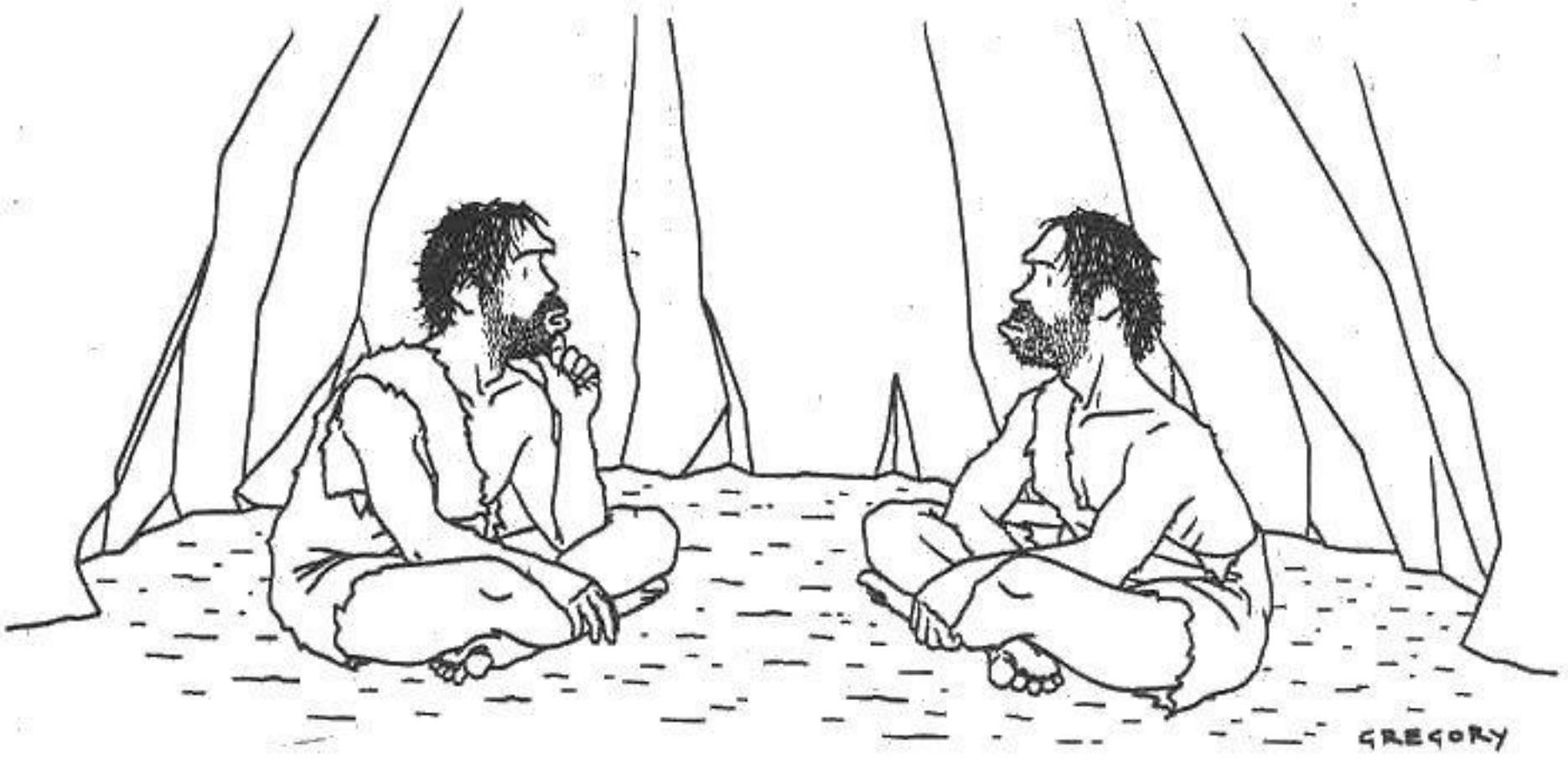
- **health(care) technologies**
- **water**
- **food**
- **shelter**
- **critical infrastructures, eg:**
  - **sanitation, transport, energy**
- **regulatory aspects**

Determinants of health:

- **economic**
- **environmental**
- **social**
- **political**

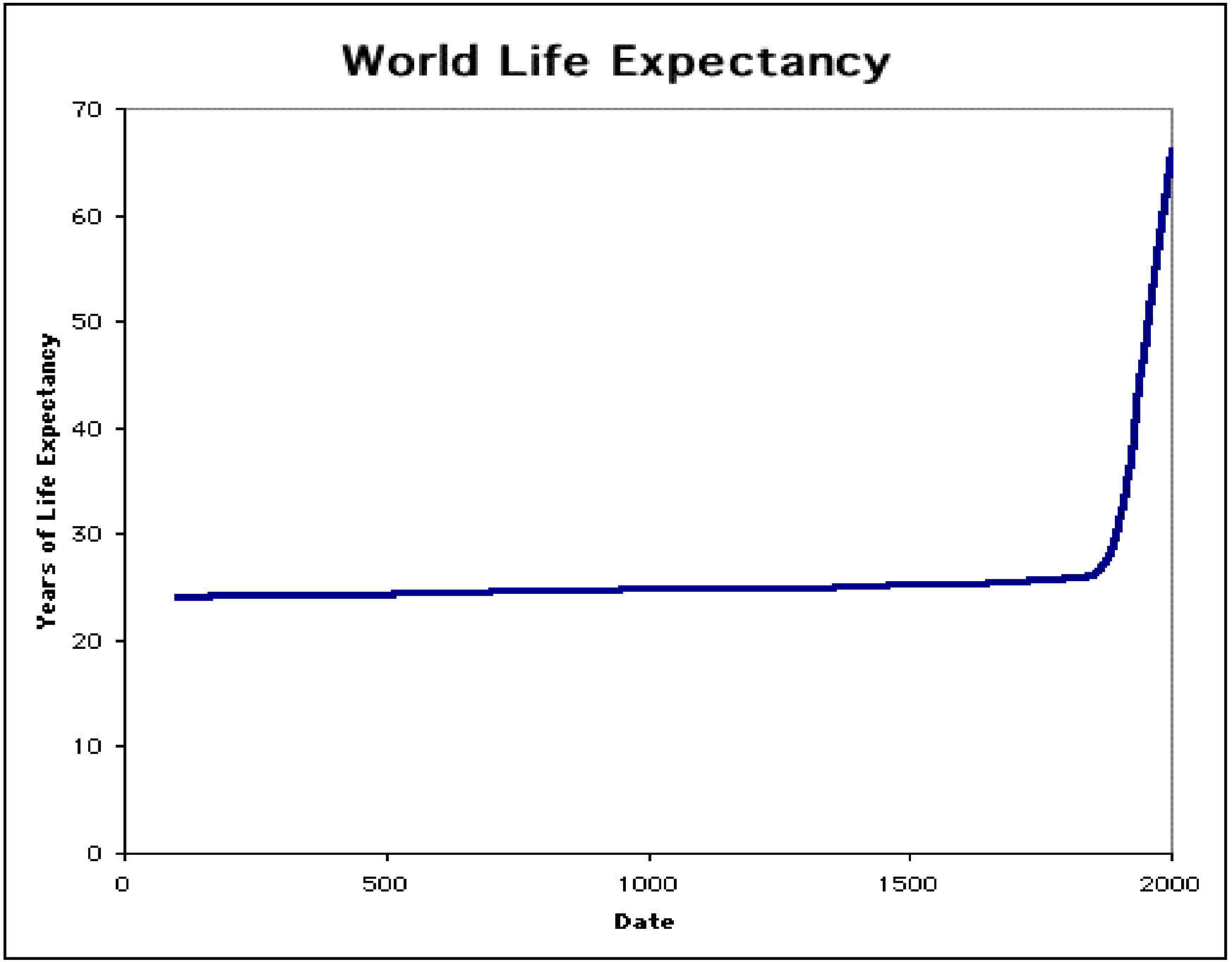
- **Diagnosis, prevention and treatment of ill-health**
- **Health promotion**

- ***Are*** **technologies good for health?**

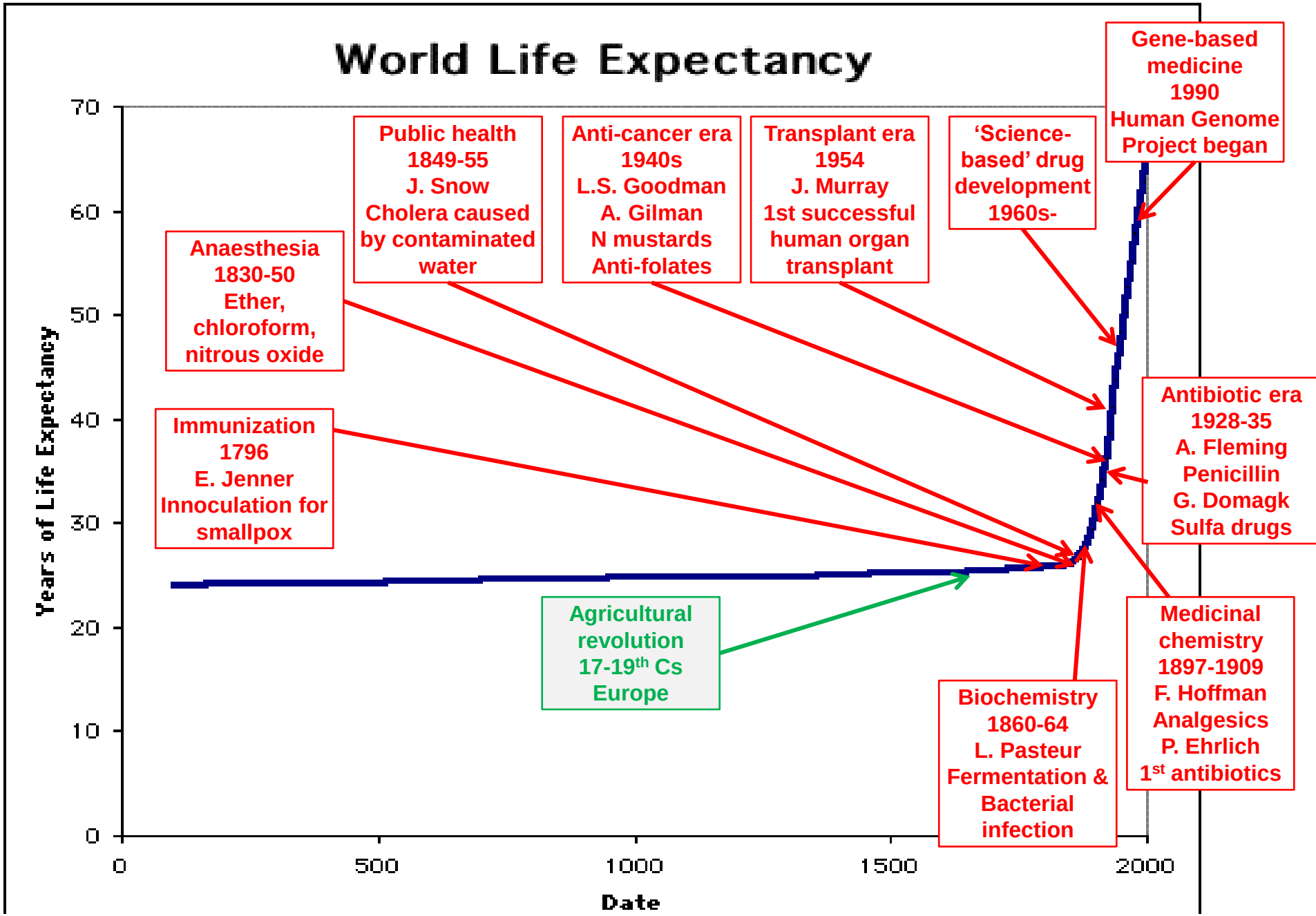


Something's just not right -- our air is clean, our water is pure, we all get plenty of exercise, everything we eat is organic and free-range, and yet nobody lives past thirty.

New Yorker, 2006 and thanks to R Terry, WHO

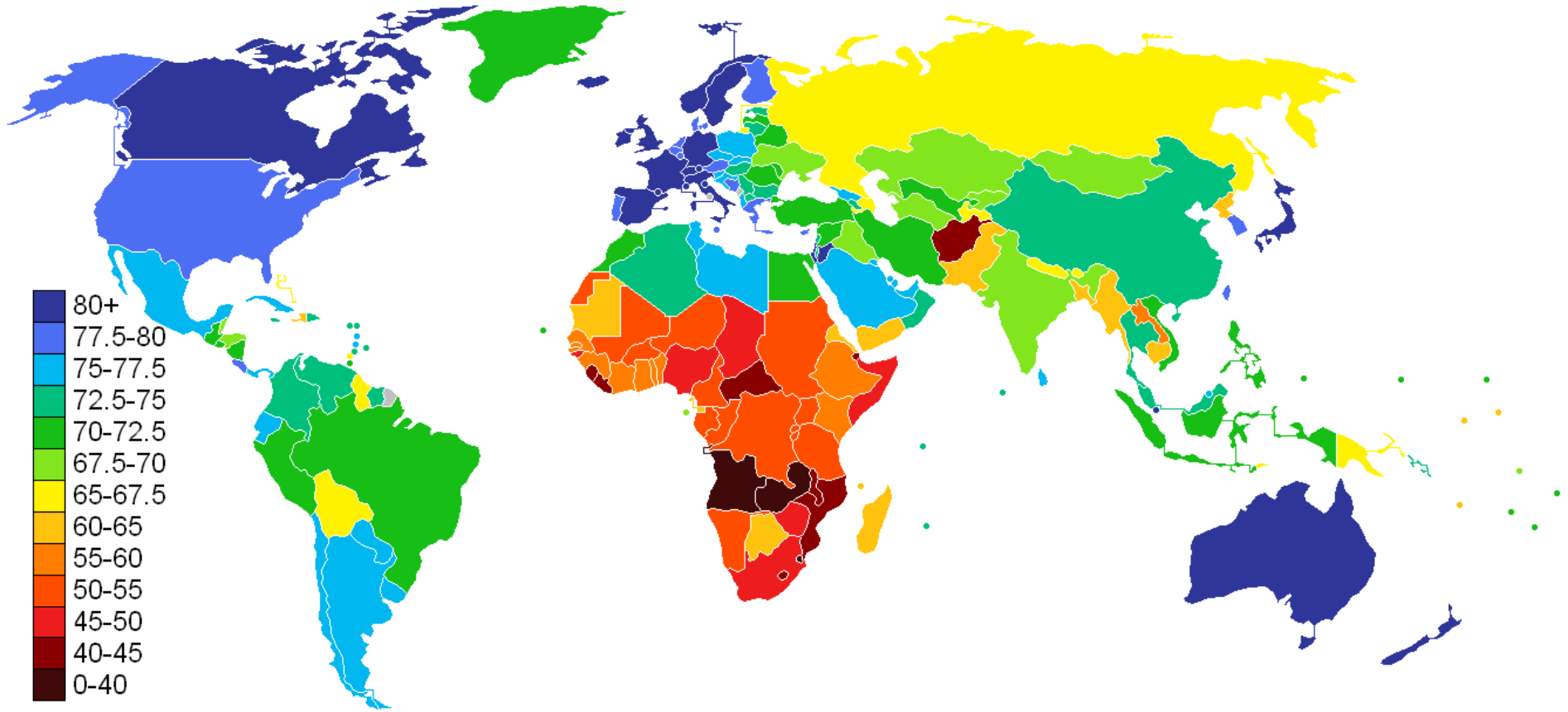


h from:
www.j-bradford-delong.net/movable_type/images2/Life_Expect_Long.gif



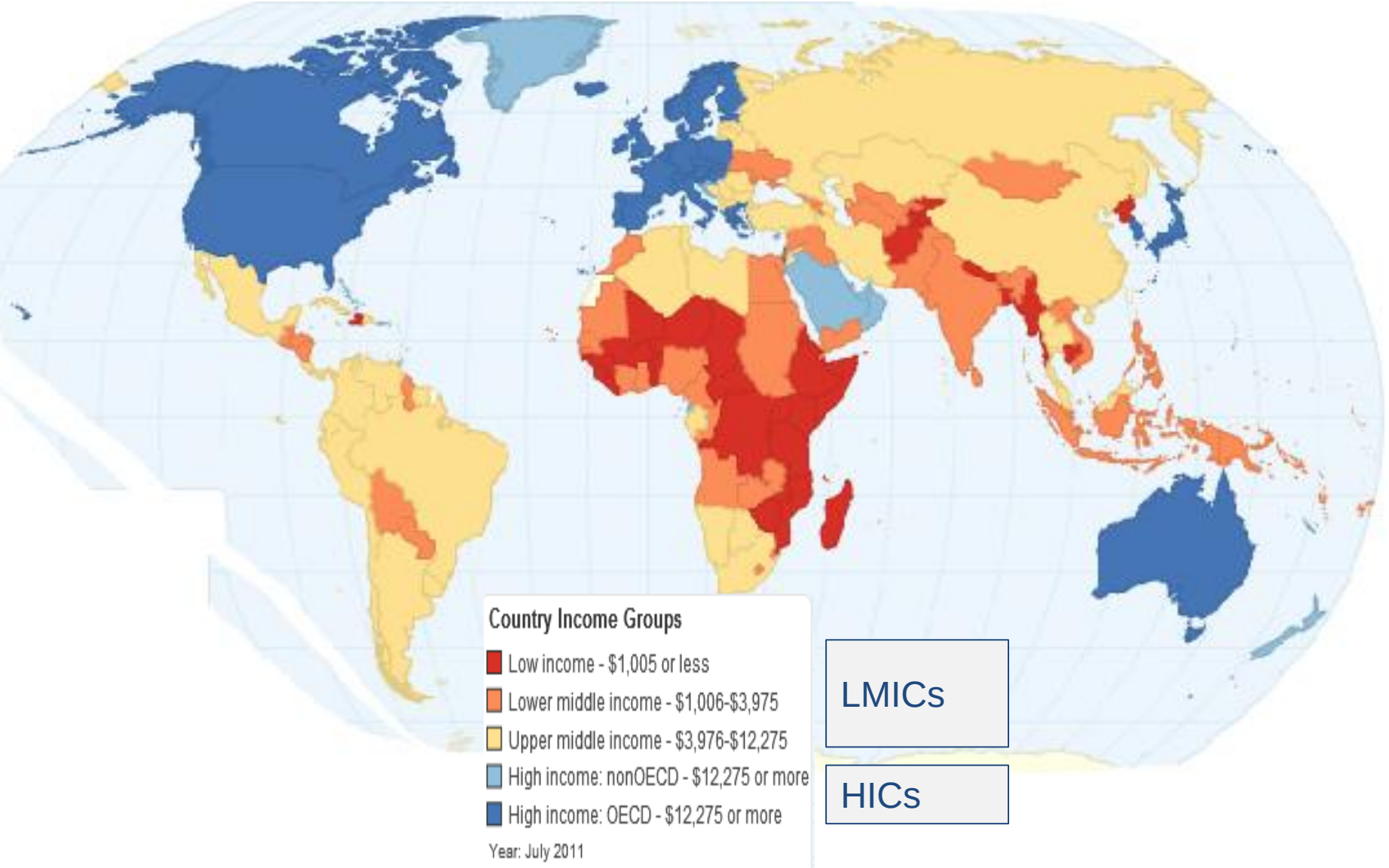
Life expectancy graph from:
www.j-bradford-delong.net/movable_type/images2/Life_Expect_Long.gif

Life Expectancy at Birth by Country: 2011 Estimates

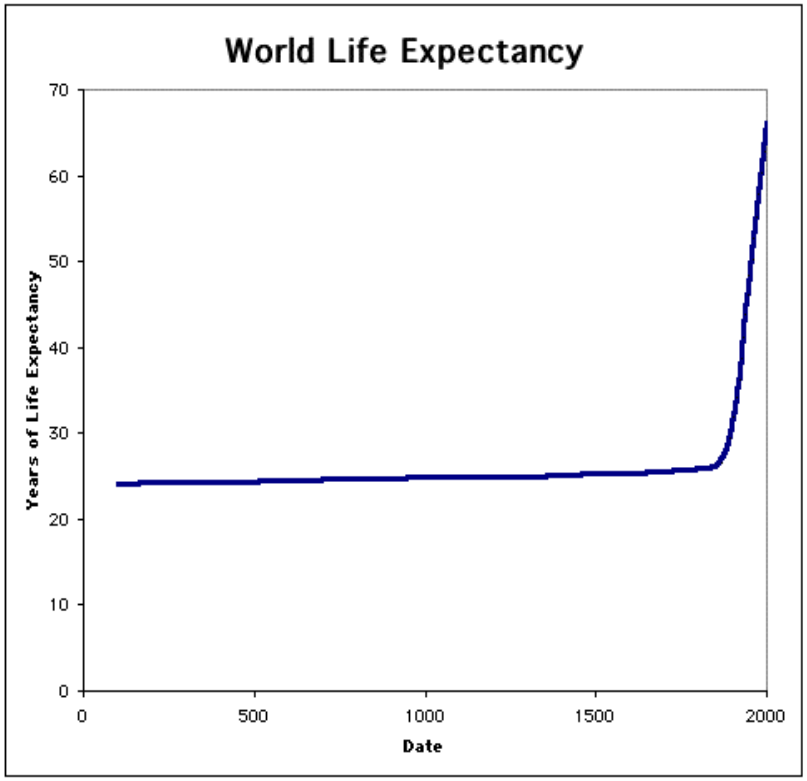


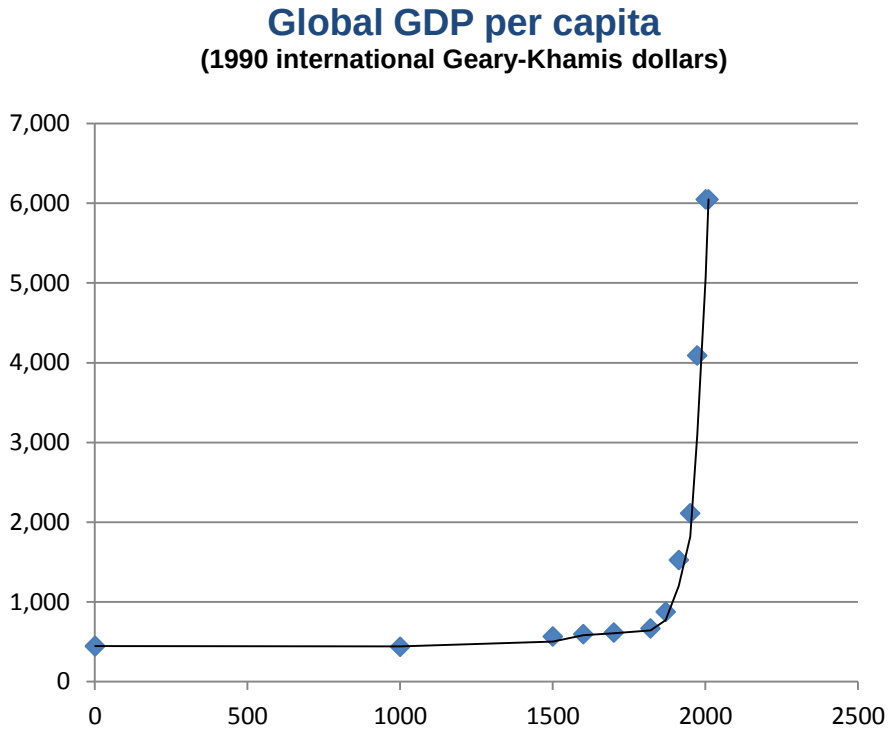
CIA World Factbook 2011; http://en.wikipedia.org/wiki/Life_expectancy

Country Income Groups 2011 (World Bank Classification)



http://chartsbin.com/view/2438



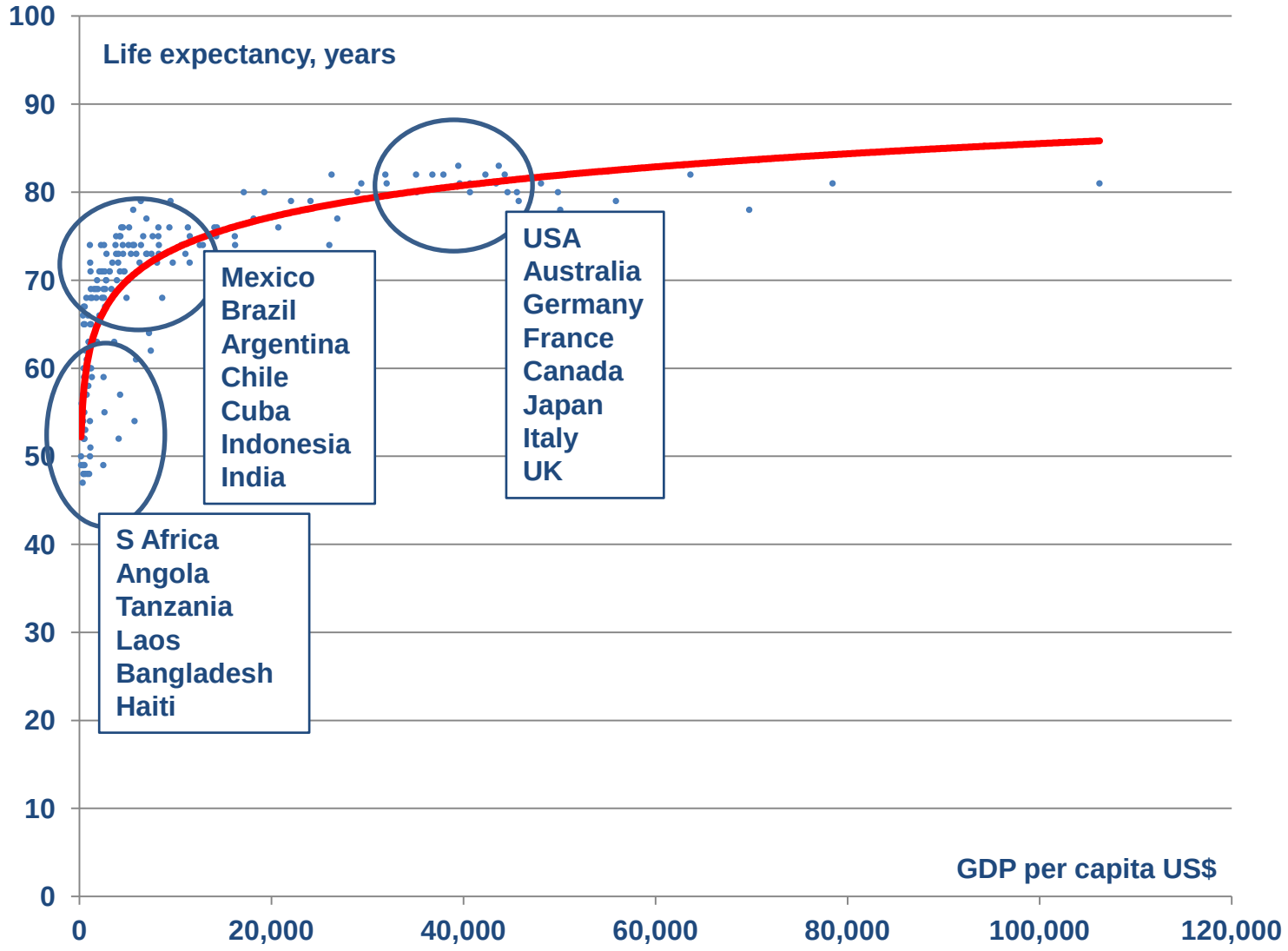


Life expectancy graph from:
http://www.j-bradford-delong.net/movable_type/images2/Life_Expect_Long.gif

GDP data from:
A. Maddison, Statistics on World Population, GDP and Per Capita GDP, 1-2001 AD. www.ggdc.net/MADDISON/oriindex.htm

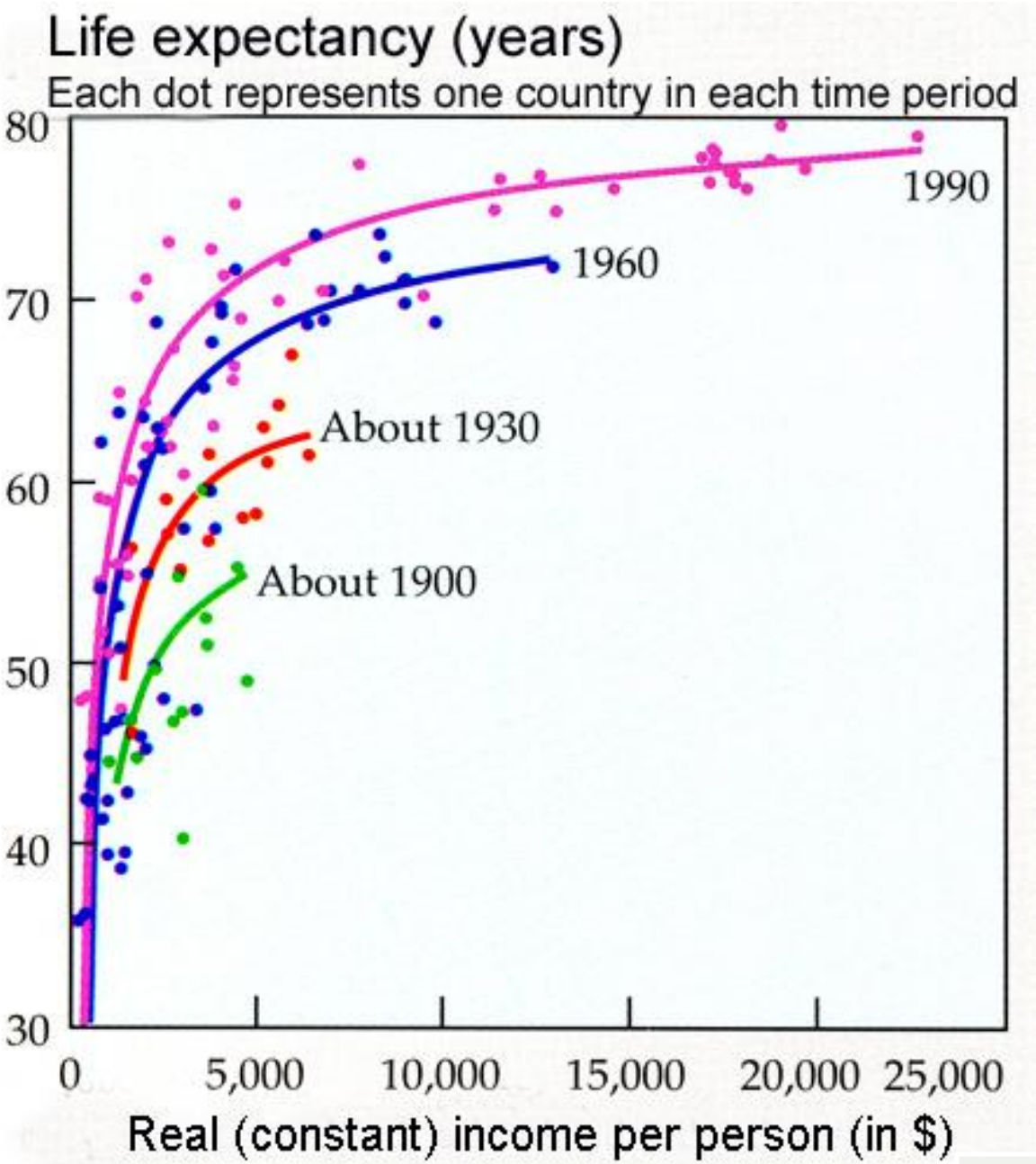
How much health do you get for your wealth?

Preston curve: Life expectancy vs GDP per capita 2009



Matlin, *Research for health,* in: *Health G20: A briefing on Health Issues for G20 Leaders,* ProBrook, London, 2011, 116-128.
http://healthg20.com/wp-content/uploads/2011/11/115-128-Stephen-A-Matlin.pdf

Preston curves 1900-1990



Preston curves 1900-1990

- **20th century mortality decline had its origin in technical progress**
  R Easterlin, *European Review of Economic History 1999*, 3: 257–94

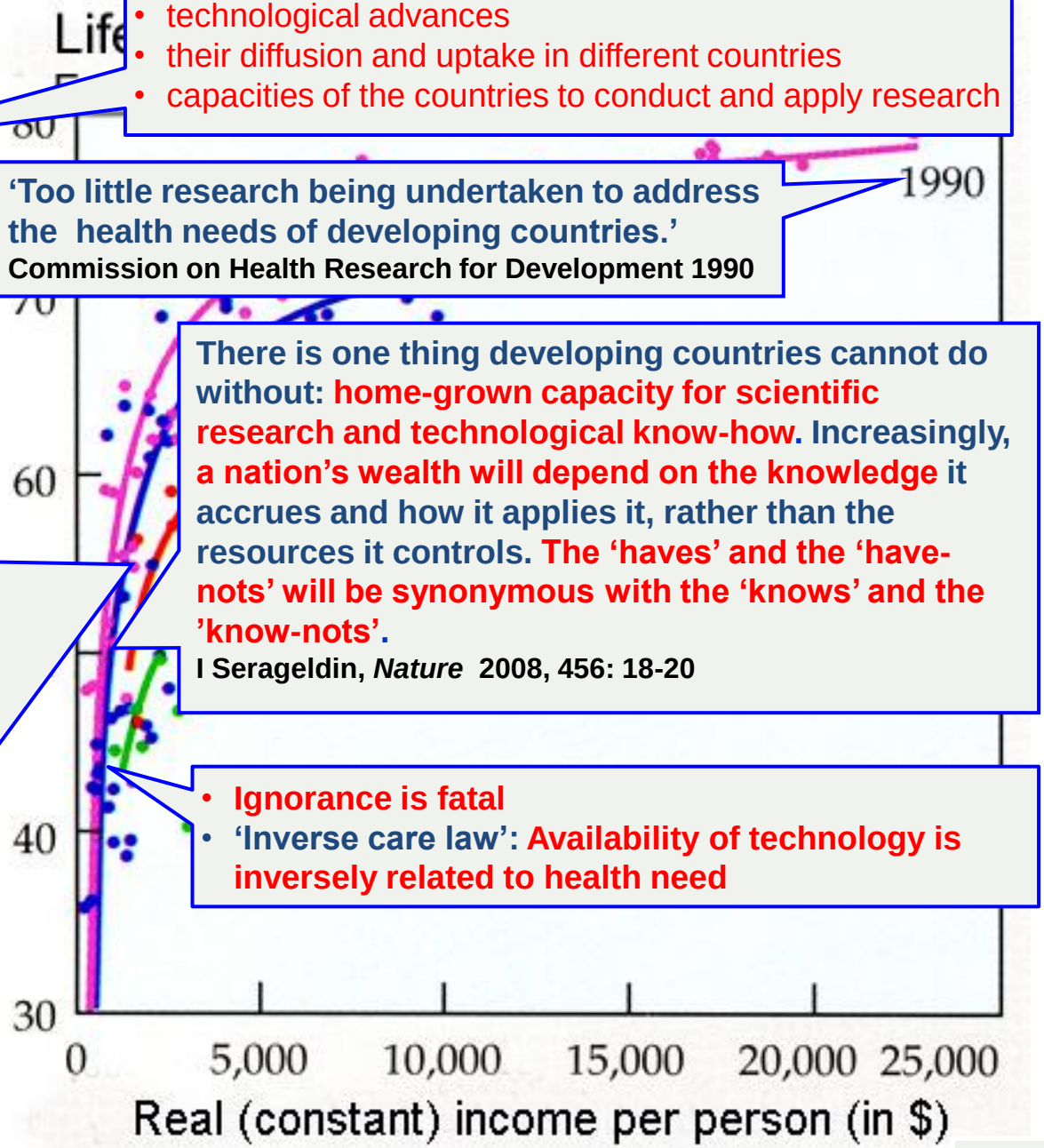
- **Much of the variation in country outcomes results from very substantial cross-country variation in the rate of technical progress**
  e.g. technical progress explains 66 % of inter-country variation in the decline in infant mortality from 1962–1987, whereas change in income explains 9 %
  D Jamison, *Disease Control Priorities in Developing Countries (DCP2), World Bank 2006*

- technological advances
- their diffusion and uptake in different countries
- capacities of the countries to conduct and apply research

'Too little research being undertaken to address the health needs of developing countries.'
Commission on Health Research for Development 1990

There is one thing developing countries cannot do without: home-grown capacity for scientific research and technological know-how. Increasingly, a nation's wealth will depend on the knowledge it accrues and how it applies it, rather than the resources it controls. The 'haves' and the 'have-nots' will be synonymous with the 'knows' and the 'know-nots'.
I Serageldin, *Nature* 2008, 456: 18-20

- **Ignorance is fatal**
- **'Inverse care law': Availability of technology is inversely related to health need**



- ***What*** **technologies are good for health?**

Technologies for global health

- Health(care) technologies include:
  - pharmaceutical drugs, vaccines, diagnostics
  - medical devices, surgical instrumentation
  - surgical procedures
  - processes to ensure patient safety
  - advanced wound-care
  - orthopaedics, prosthetics
  - health information technologies
  - telemedicine, eHealth, mHealth,
  - medical imaging
  - medical and surgical robotics
  - laboratory facilities for a range of R&D and process activities including:
    - clinical trials, medical diagnosis & screening, life sciences, toxicology, genetics, drug delivery, medical engineering, information technology, chemical & biochemical analysis.
- Clean water
- Healthy food
- Health-promoting/sustaining shelter
- Critical infrastructures, eg:
  - transport
  - energy
  - sanitation
  - communications
  - supply chains
- Regulatory aspects

- Prevention, diagnosis, and treatment of ill-health
- Health promotion

- ***In what context*** **are technologies good for health?**

In the *local* conditions, must be:

- **Safe**
- **Effective**
- **Affordable**
- **Applicable**
- **Accessible**

‘Frugal’ technologies

- **Reducing costs**
- **Reducing complexities in use**
- **Expanding utility in challenging settings (e.g. environment; poverty)**

LMIC constraints

- **Purchase/running costs**
- **Workforce shortages: Doctors, nurses, technicians**
- **Maintenance**
  40% of health care equipment in LMICs out of service
  <1% of health care equipment in HICs out of service

Technologies for global health

Glocal

Many problems have a dual character, involving:

- **a global dimension which requires joint international action**
- **a local adaptation, application or focus**

The globalization slogan:
“think globally, act locally’

is evolving into a ‘glocal” principle:
“think and act globally and locally”

Frugal technologies/frugal innovation

Concept origin:

1. **'Appropriate technology' movement**
   - Mahatma Gandhi:1920s-30s, advocated for small, local and predominantly village-based technology to help India's villages become self-reliant
   - Concept 'intermediate technology' or 'appropriate technology' articulated by Fritz Schumacher in 1960s papers and in his 1972 book '*Small is Beautiful: Economics as if People Mattered*'. Refers to technology that is:
     - small-scale, labour-intensive, energy-efficient, environmentally sound, locally controlled
     - seen as an alternative to transfers of capital-intensive technology from HICs to LMICs
   - Examples of appropriate technology: bike- and hand-powered water pumps

2. **Increasingly popular 'sustainable development' movement incorporates many of the ideas of 'appropriate technology'**

3. **Some industries have taken up the idea of 'frugal innovation' – an alternative model considered more suitable for LMICs:**
   - e.g. Electrocardiograms (ECGs) are the most widely performed cardiac test in HICs. After encountering various constraints to the use of standard ECG (US2,000, heavy, bulky, requires skilled operator and elaborate service support) in rural India, General Electric developed the Mac 400 ECG (US$ 800) for rural India that is portable, battery-operated, easy-to-use, and easy-to-repair. Reduces cost from US$20 to US$1 per patient.

     www.businessweek.com/articles/2012-04-17/the-case-for-frugal-thinking
     www.economist.com/node/15879359

Reverse engineering

Technology 'backwards': from product to process

- process of discovering the technological principles of a device, object, or system through analysis of its structure, function, and operation
- Important example in global health:
  - 'Generic' manufacture of pharmaceuticals in India: until India accession to World Trade Organization in 2005, only ***process*** patents recognized, not ***product*** patents: so if an Indian company could find a non-patented way to make a branded pharmaceutical, it would side-step the product patent and make its own version. Applied to dozens of drugs – India became the 'pharmacy of the Third World'.
    www.usitc.gov/publications/332/working_papers/EC200705A.pdf

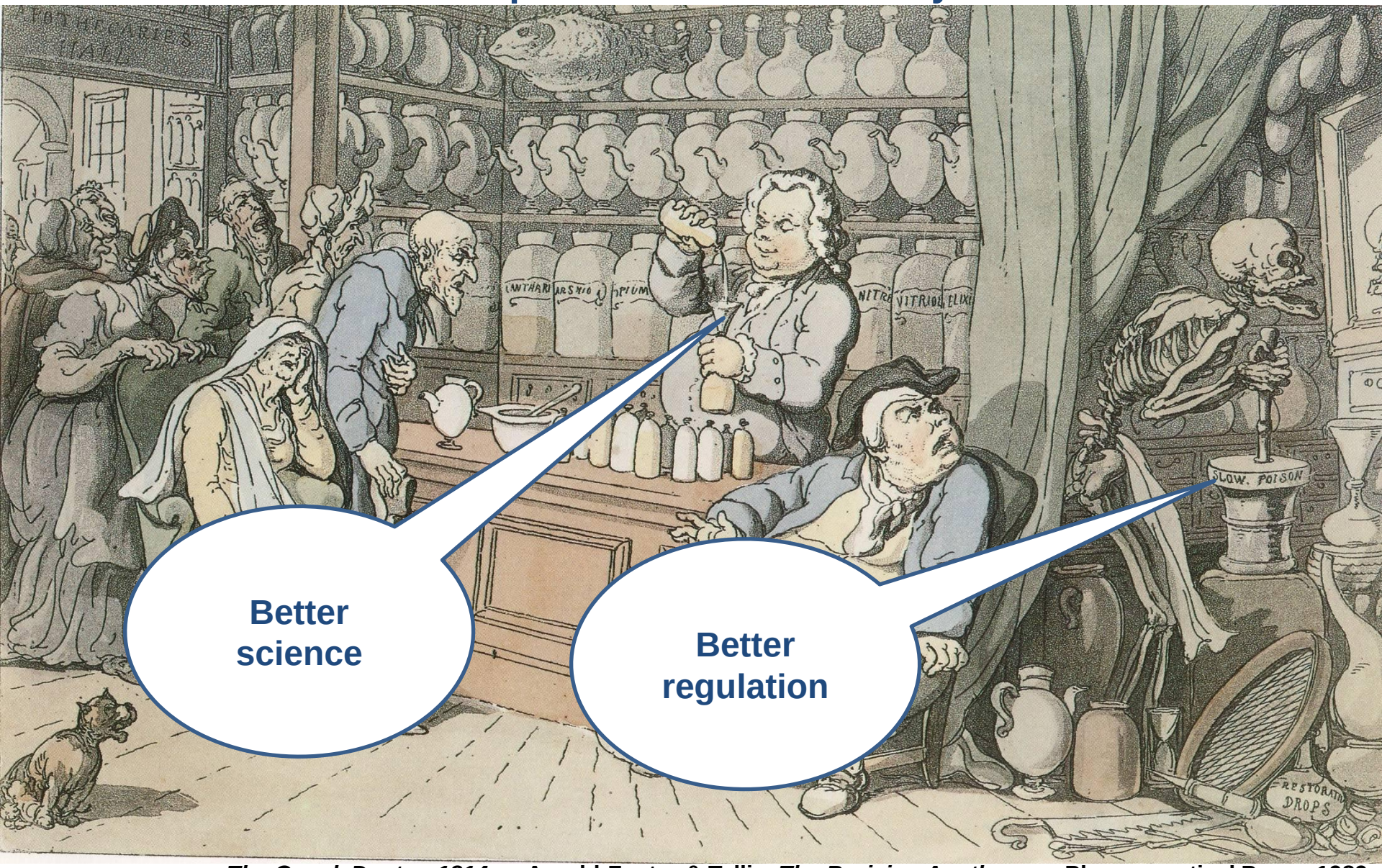
Reverse innovation

'Trickle-up innovation': an innovation seen first, or likely to be used first, in LMICs before spreading to HICs.
So, a 'frugal technology' first developed for LMIC use and then adopted by HICs would be an example, such as:

- Many creative uses of mobile phones for eHealth first established 'where there is no doctor'
- Oral rehydration therapy, a simple treatment for diarrhoea developed in India and Bangladesh, using oral rehydration solution (ORS) of sugar and salt: has now saved millions of lives across the world.
  www.ncbi.nlm.nih.gov/pmc/articles/PMC1036912/pdf/medhist00037-0005.pdf

Technologies for global health
Example 1: pharmaceuticals

The pharmaceutical industry

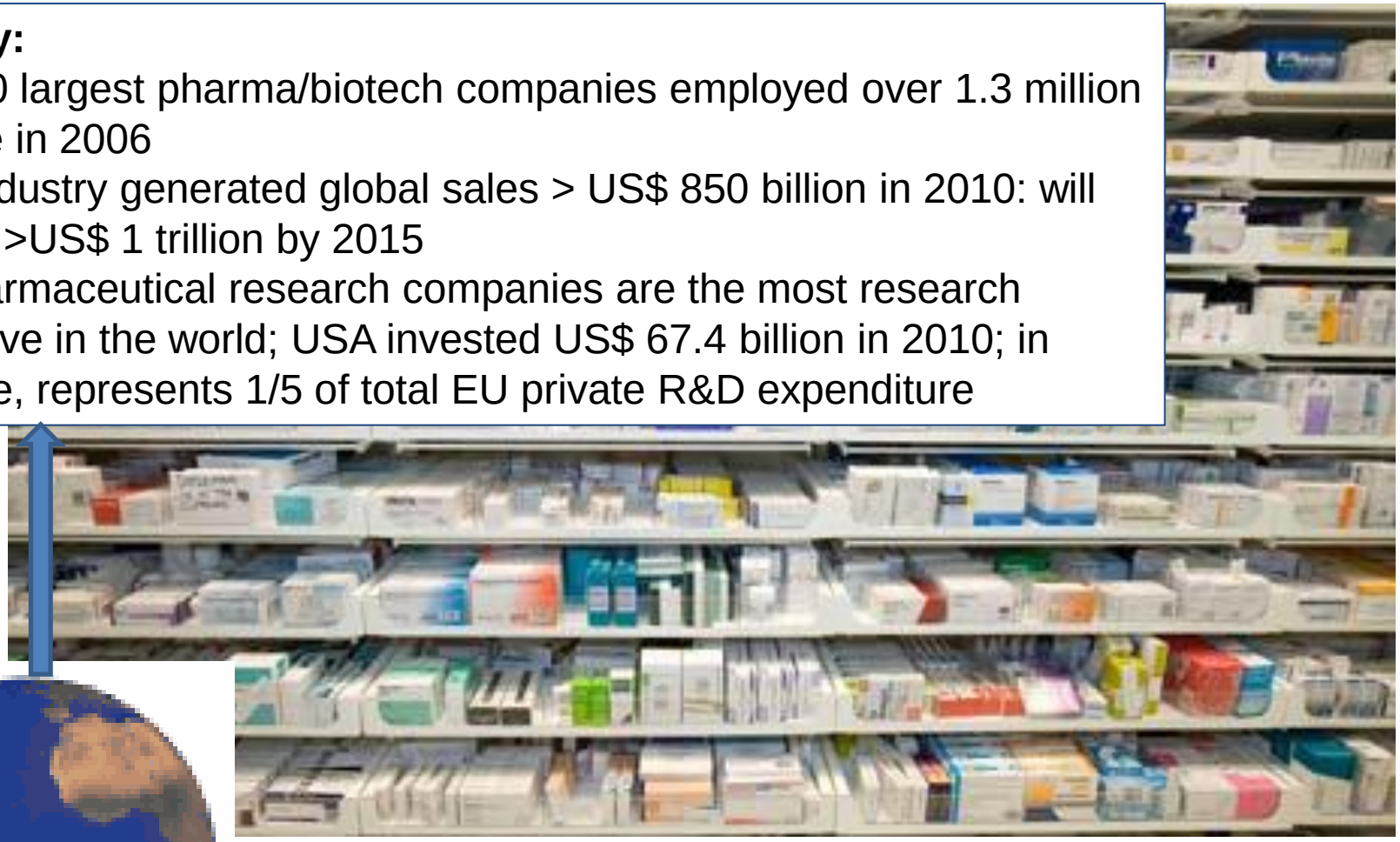


The Quack Doctor, 1814. Arnold-Foster & Tallis, *The Bruising Apothecary*, Pharmaceutical Press, 1989

The pharmaceutical industry

Globally:

- The 20 largest pharma/biotech companies employed over 1.3 million people in 2006
- The industry generated global sales > US$ 850 billion in 2010: will rise to >US$ 1 trillion by 2015
- biopharmaceutical research companies are the most research intensive in the world; USA invested US$ 67.4 billion in 2010; in Europe, represents 1/5 of total EU private R&D expenditure



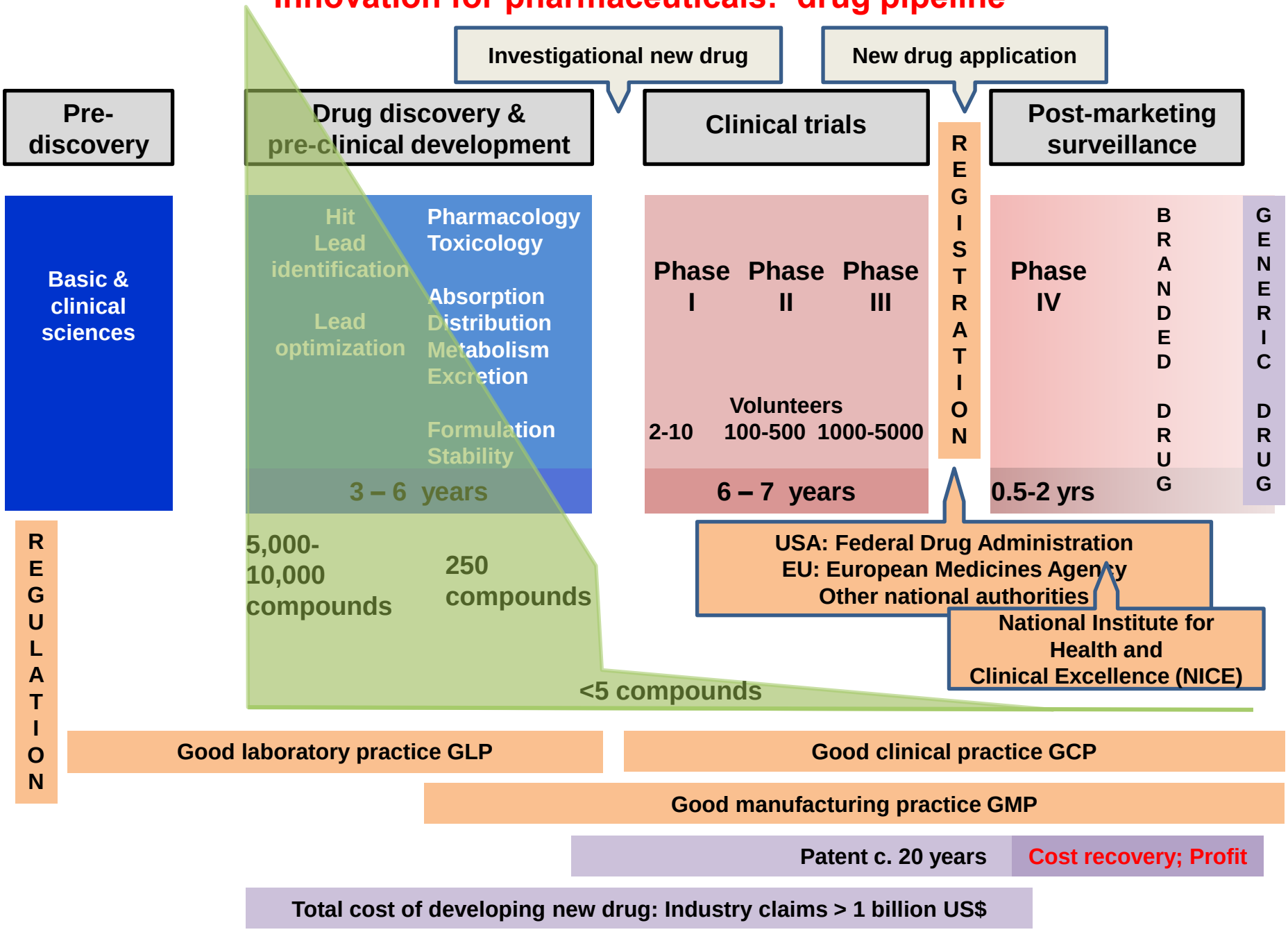
Pharmacologic and Therapeutic Categories

- Anti-infective Agents
- Cancer Drugs
- Hormones, Diabetes And Related Drugs
- Heart And Circulatory Drugs
- Respiratory Agents
- Gastrointestinal Drugs
- Genitourinary Drugs
- Central Nervous System Drugs
- Pain Relief Drugs
- Neuromuscular Drugs
- Supplements
- Blood Modifying Drugs
- Topical Products
- Miscellaneous Categories

Prevention, diagnosis and treatment of:

- Communicable diseases
- Metabolic disorders
- Degenerative conditions

Innovation for pharmaceuticals: 'drug pipeline'



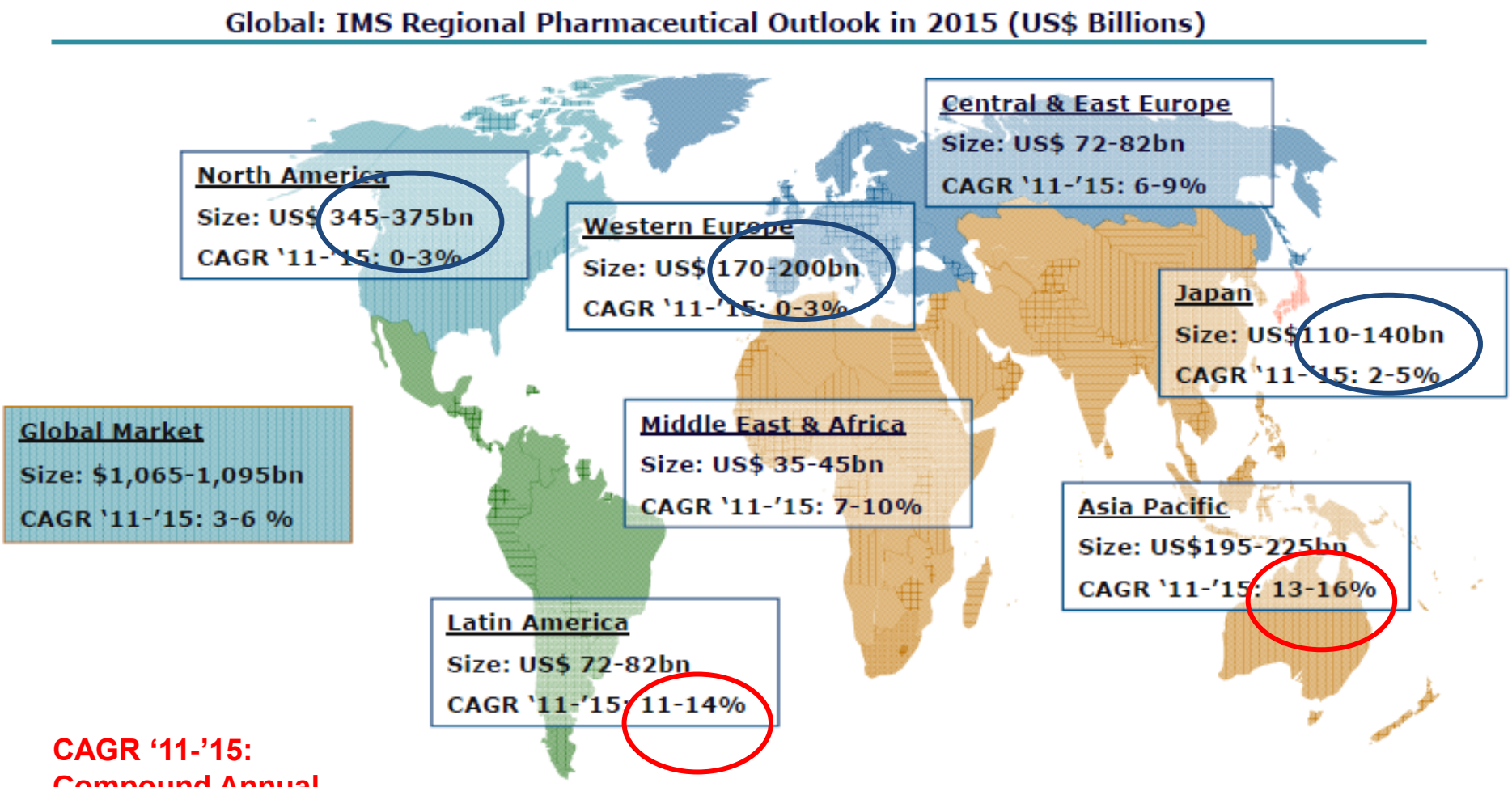
Technologies for global health
Example 1: pharmaceuticals

The geography of medicines

- **Drugs needed for diseases that are exclusively or predominantly found in LMICs may not be developed, because the market will not provide for cost recovery and profit.**

- **Drugs developed for diseases commonly found in LMICs may be too expensive for use in LMICs during the patent period: so there may be a time lag of many years before they become available in LMICs as cheap generics (by which time, they may have been superseded by much better new, patented drugs).**

Consumption: has been greatest in HICs but now moving to LMICs



CAGR '11-'15: Compound Annual Growth Rate 2011-2015

"Pharmerging" markets

IMS Health, Market Prognosis, Apr 2011. www.bvgh.org/LinkClick.aspx?fileticket=kMaOKGUbqgI%3D&tabid=168

Consumption: has been greatest in HICs but now moving to LMICs

"Pharmerging" markets

IMS Health, Market Prognosis, Apr 2011. www.bvgh.org/LinkClick.aspx?fileticket=kMaOKGUbqgI%3D&tabid=168

Neglected diseases/health issues

Infectious diseases

1975 Launch of UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR)

1990 Commission on Health Research for Development:
'Too little being spent on health research for the needs of developing countries'

1997 Rockefeller Foundation created International AIDS Vaccine Initiative and followed with other Product Development Partnerships (PDPs) to tackle neglected diseases. Later, Bill & Melinda Gates Foundation (BMGF) invest in PDPs, especially for HIV/AIDS, TB, Malaria

2000 Millennium Development Goals (especially: HIV/AIDS, TB, Malaria)

2002 *Drug development for neglected diseases: a deficient market and a public-health policy failure.*
P. Trouiller et al, Lancet 359: 2188-94:
'Of 1393 new chemical entities marketed as drugs between 1975 and 1999, only 16 were for tropical diseases and tuberculosis'
http://msf.openrepository.com/msf/bitstream/10144/28441/1/Access%20Trouiller%202002.pdf

2005 M. Moran et al. New Landscape of Neglected Disease Drug Development
www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_publishing_group/documents/web_document/wtx026592.pdf
PDPs successful in creating a health pipeline of candidate drugs for neglected diseases – but much more money needed from governments

2012 Completion of 5-year G-FINDER study funded by BMGF: PDPs continuing success in creating a health pipeline of candidate drugs for neglected diseases – more money now available (despite global financial crisis) but much more money still needed to sustain all parts of pipeline
www.policycures.org/g-finder2012.html

Neglected diseases/health issues

Fertility regulation

1967 United Nations Fund for Population Activities (UNFPA) established, renamed United Nations Population Fund in 1987. Aims at achieving universal access to sexual and reproductive health (including family planning).

1975 Launch of UNDP/UNICEF/UNFPA/WHO/World Bank Special Programme of Research, Development and Research Training in Human Reproduction (HRP)

- ***Hundreds of millions of couples [in LMICs] do not have access to safe, effective, affordable and acceptable methods of family planning***
- ***Industry losing interest in developing new contraceptive agents, even for HICS, largely as a result of litigation system in USA.***

1977 Program for the Introduction and Adaptation of Contraceptive Technology (PIACT) founded in Seattle: later became Program for Appropriate Technology in Health (PATH).

2012 UNFPA 'State of the World's Population 2012': 222 million women in LMICs are unable to exercise their right to family planning because they lack access to contraceptives, information and quality services

World still lacks:

- Access to safe, effective, acceptable, convenient, affordable contraception for >>100 million couples
- Safe, effective, acceptable, affordable, reversible, systemic agent for male fertility regulation

Neglected diseases/health issues

Noncommunicable diseases

- Includes cancer, diabetes, heart disease, stroke, chronic obstructive pulmonary disorders, mental and neurological conditions
- Massive and rising problem in ALL parts of the world, including LMICs: accounts for >63% of current annual global deaths.
- Many of the determinants are related to ‘lifestyle’ (diet, exercise, tobacco) and environment – hence largely preventable. But also related to ageing populations.

Many treatments available

- Largest area of activity for the global pharmaceutical industry
- Many treatments very expensive; heavy burden for health systems in HICs and often unavailable or unaffordable in LMICs

Noncommunicable diseases

Polypill for cardiovascular disease

- 2003 Nicholas Wald, Malcolm Law - *A strategy to reduce cardiovascular disease by more than 80%*
  - Based on data from many trials relating to the individual components:
    - postulated using a combination of 6 well known, cheap medications in one pill (the 'polypill') to reduce risk of cardiovascular disease.
    - suggested polypill could reduce mortality due to heart disease and strokes by up to 80%.
    - potentially cheap, few side effects (in perhaps 10-15% of recipients).

- Principles: reducing blood pressure, cholesterol and taking a low dose of aspirin to help prevent heart disease and stroke.
  The polypill would contain three blood pressure-lowering medications at low dose:
  - a diuretic e.g. hydrochlorothiazide
  - a beta-blocker e.g. atenolol
  - an ACE inhibitor e.g. lisinopril

  Combined with
  - a statin e.g. simvastatin to lower serum cholesterol
  - aspirin at a dose of 75 mg to reduce blood clotting
  - folic acid – reduces level of homocysteine in the blood (another risk factor for heart disease)

- GP can currently prescribe all components of polypill separately for patients. Polypill could improve adherence to treatment; and if delivered at a low price reduce the cost to the health system and also make treatment more affordable in low-income countries.

- Ingredients of polypill are off-patent: would make polypill quite cheap (< £70 /US$100 per year), but little financial incentive for pharmaceutical companies to pay the high costs of a clinical trial.

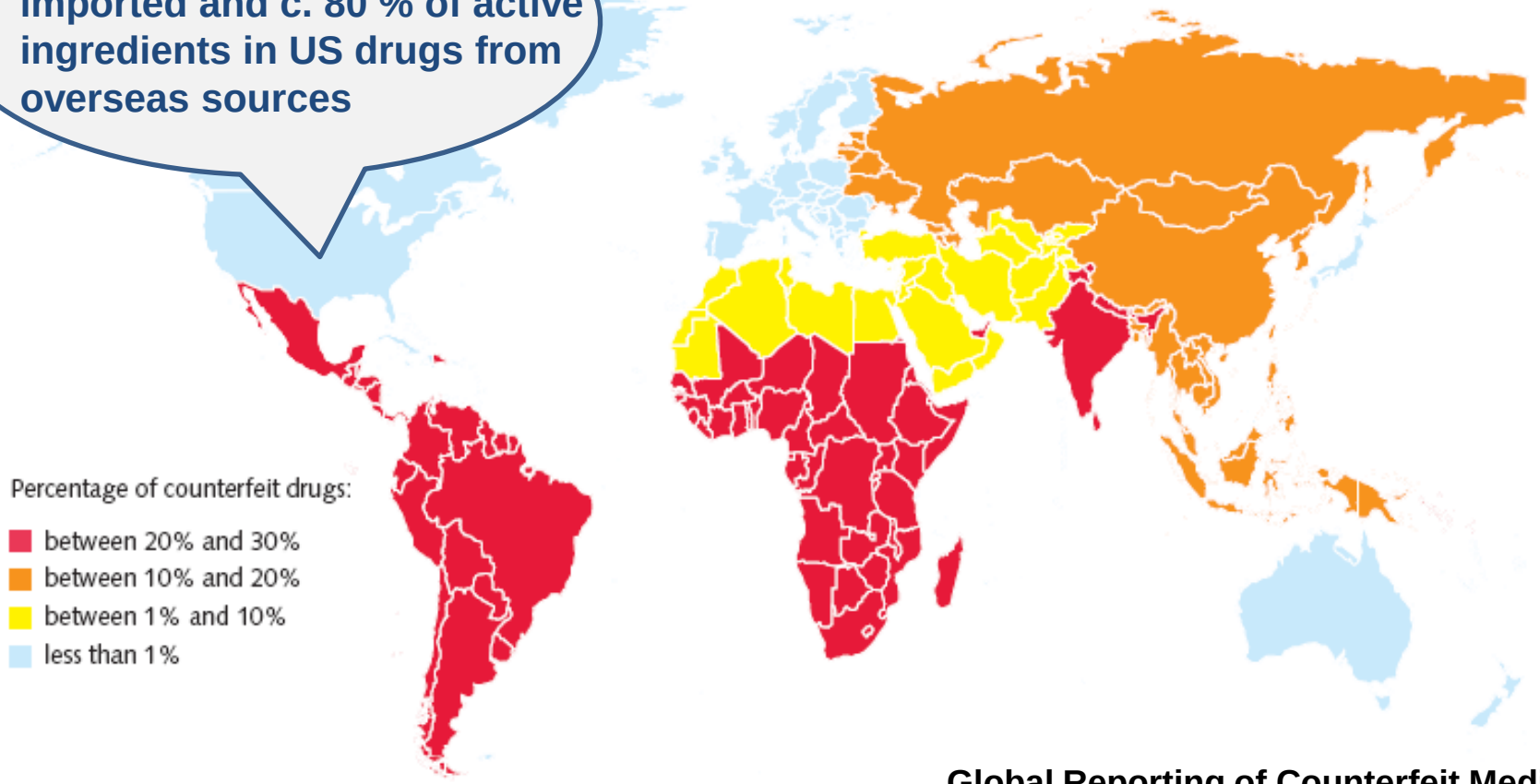
- Polypills currently available in India. Cardiologists in Spain currently developing a polypill for secondary cardiovascular prevention, in collaboration with Ferrer-Internacional (Barcelona).

Counterfeit drugs

Its a fake world: Counterfeit drugs becoming increasingly available

- Estimated counterfeit drug sales worth US$ 75 billion globally in 2011
- Counterfeit medicines estimated to constitute >10% of global medicines market: c. 1% in HICs and 10-50% in LMICs

c. 40 % of drugs in USA imported and c. 80 % of active ingredients in US drugs from overseas sources



Global Reporting of Counterfeit Medicines
http://ec.europa.eu/internal_market/indprop/docs/conf2008/wilfried_roge_en.pdf

Counterfeit drugs

June 2011

Belgian man extradited from Costa Rica to USA convicted of operating fraudulent internet pharmacy and jailed for 4 years

- **Sold $1.4 million misbranded and counterfeit drugs and controlled substances**
- **An international business:**
  - **customer service call centre in Philippines**
  - **Western Union wire transfers via the Philippines, Costa Rica and USA**
  - **credit card processors in the Netherlands**
  - **website hosting service in USA**
- **The Canadian co-defendant remains a fugitive.**

www.fda.gov/ICECI/CriminalInvestigations/ucm257945.htm

Counterfeit drugs

Jan 1999 - Oct 2000 WHO: 46 reports from 20 countries (60% LMICs)

Counterfeit drugs included antibiotics, hormones, analgesics, steroids, antihistamines:

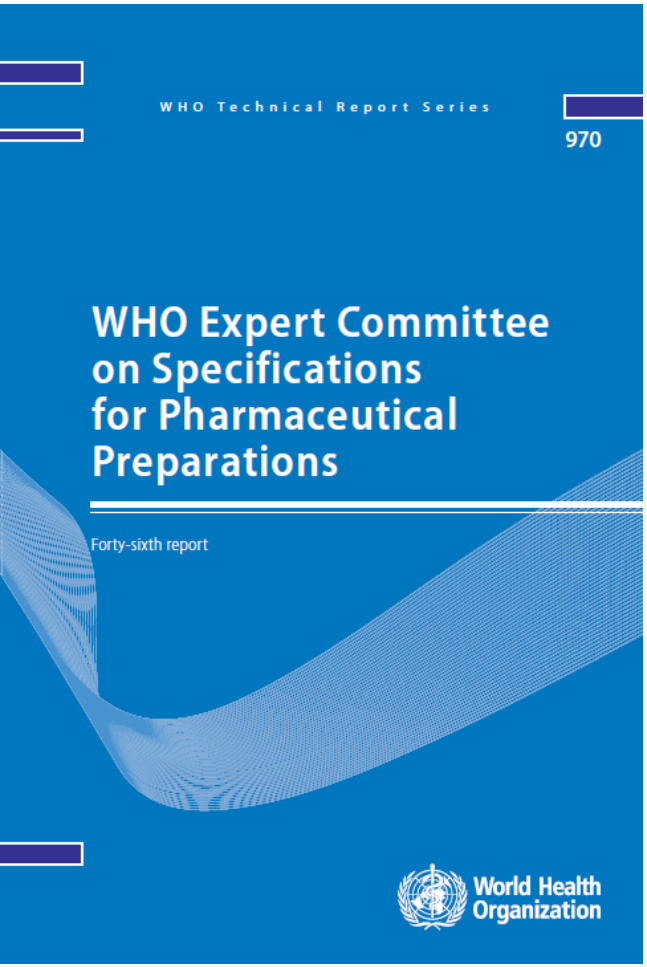
- **without active ingredients, 32.1%;**
- **with incorrect quantities of active ingredients, 20.2%;**
- **with wrong ingredients, 21.4%,**
- **with correct quantities of active ingredients but fake packaging, 15.6%;**
- **with high levels of impurities and contaminants, 8.5%**

No simple solution

- **Problem has reached a global dimension and needs a global approach**
- **Absence of, or weak, drug regulation**

WHO, Geneva, 2011.
www.who.int/medicines/services/counterfeit/overview

Counterfeit drugs



Every country, regardless of its stage of development, should consider investment in an independent national drug quality control laboratory

WHO Expert Committee on Specifications for Pharmaceutical Preparations 29th Report, 1984
http://whqlibdoc.who.int/trs/WHO_TRS_704.pdf

Absence of or weak drug regulation

- At present, of 191 WHO member states **c. 20% have well developed drug regulation**. Of remainder, c. 50% implement some drug regulation; another 30% either have no drug regulation in place or a very limited capacity that hardly functions.
- **Inadequate resources** for drug regulation activities and **absence of training** of national drug regulatory authorities' personnel may also manifest itself as **inefficiency** and **incompetence** of national drug regulatory authorities.

General Information on Counterfeit Medicines, WHO 2012
www.who.int/medicines/services/counterfeit/overview/en/index1.html

Counterfeit drugs

Technologies to prevent/identify counterfeits

No single approach: combination essential, especially as dosage and packaging can become separated

'Simplified'/rapid analytical screening

- **China: lab in a van – > 400 vehicles in countryside, equipped with mobile analysis equipment, including spectrometers to analyse spectrum a compound emits when exposed to near infra-red light; other test kits including high performance liquid chromatography , thin-layer chromatography, colorimeters.**
- **Global Pharma Health Fund minilab – used in 70 countries, mainly Africa, Asia, Western Pacific. Combines colour-testing and chromatography: packs into two very large suitcases and costs US$10,000 (GPHF subsidises this by US$5,000 and throws in the US$2,000 reference drugs for free). Consumables cost up to US$4 per test.**
- **Increasing emphasis now on developing specific spot-tests for field use to confirm active ingredients.**

On-dosage technologies

- **Oral solid-dosage coating technologies that are difficult to reproduce**
  - **enrobes tablet core with tightly adhering film : very difficult to fake; tamper resistant; tamper-evident**
- **Unique colours, printed bar-codes, logos and images on tablet**
- **Non-visible, encrypted security features and chemical markers**

Packaging technologies

- **Track-and-trace methods on product packaging, including:**
  - **Radio frequency identification: e.g. Tags attached to drug packaging. Scan with pen reader, which lights green for a positive verification.**
  - **2D barcoding**
  - **Mobile phone system: mPedigree**
    Scratch patch revealing unique identifier code: text by mobile phone to a central number and receive confirmation of identity within seconds.

www.scidev.net/en/health/detecting-counterfeit-drugs/features/fighting-fake-drugs-with-high-tech-solutions-1.html
http://pharma.about.com/od/Government_IP/i/Preventing-Counterfeit-Drug-Trade.htm

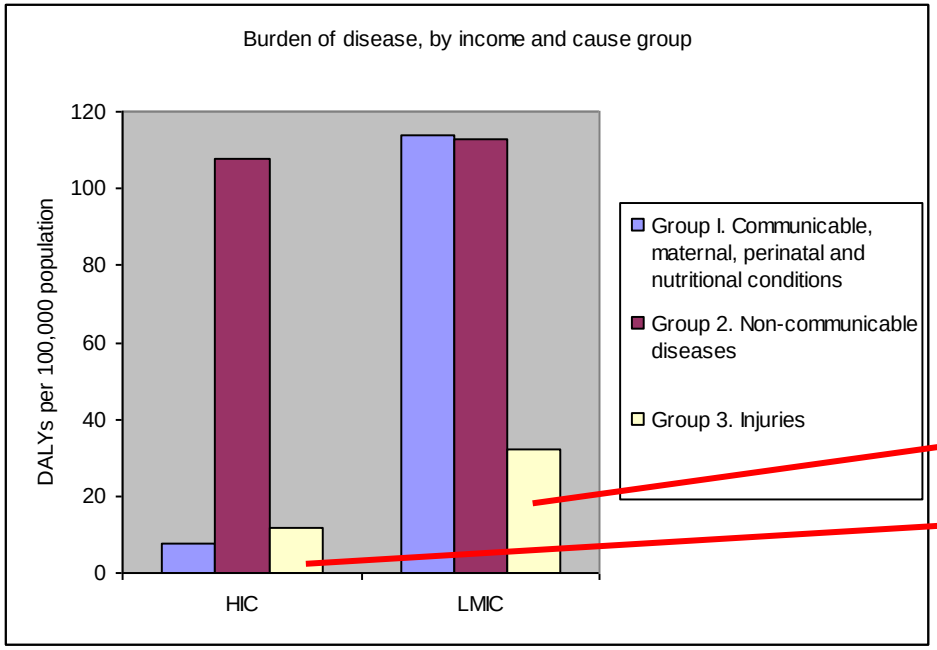
Counterfeit drugs

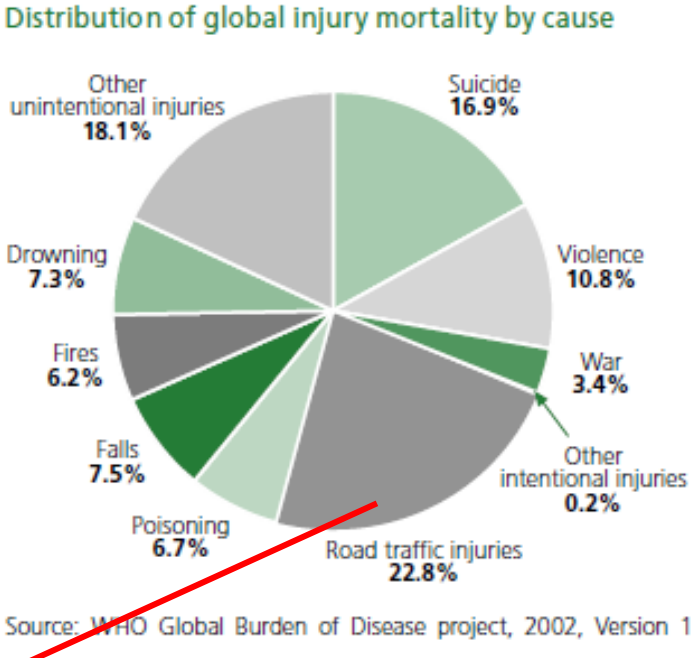
Technologies to prevent/identify counterfeits

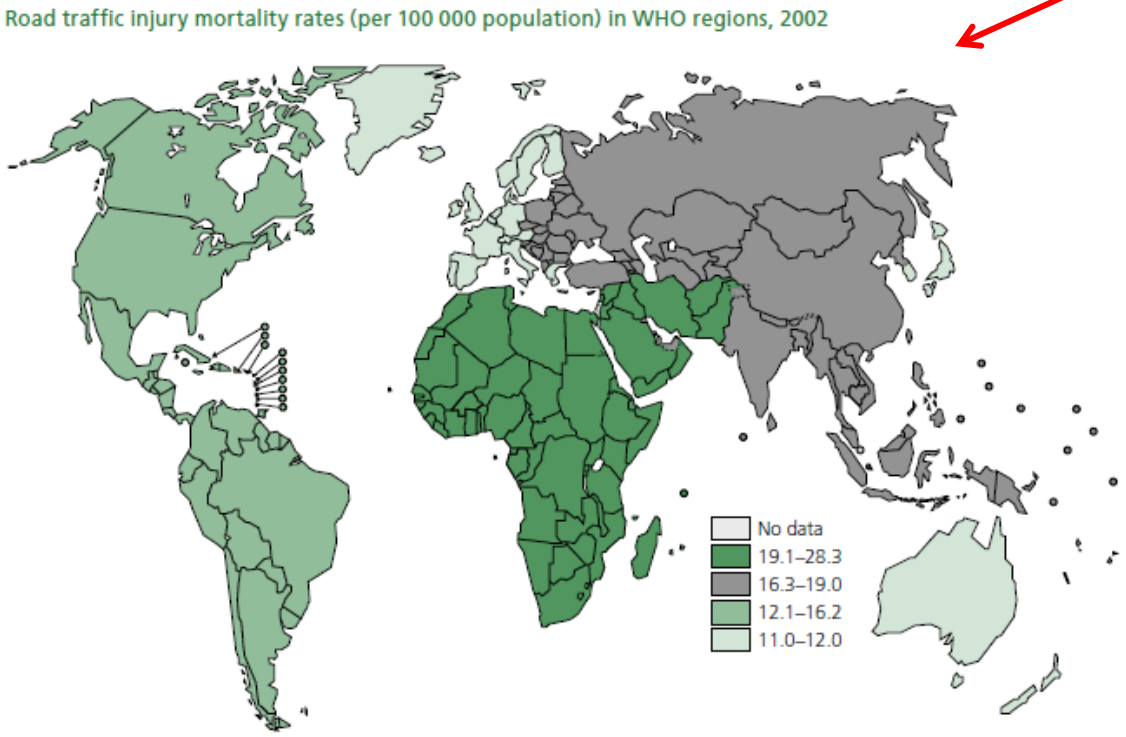
Predicted: World market for pharmaceutical anti-counterfeiting technology will rise to roughly US$1.2 billion in 2015

Visiongain Report 29October 2012
www.healthcareitnews.com/news/rx-anti-counterfeiting-technologies-reach-12b-2015

Technologies for global health
Example 2: Road traffic injuries







World report on road traffic injury prevention. WHO 2004

- c. 1.2 m deaths, 20-50 m injuries/year
- Costs countries 1-2% of their GNP
- c. 90% of road traffic deaths occur in LMICs, which comprises two thirds of the global population.
- Rising: will become 5th leading cause of death by 2030
- Compared to other causes of mortality & morbidity, this is a neglected field

http://whqlibdoc.who.int/publications/2004/9241562609.pdf

Road traffic injuries

Factors involved in road traffic injuries

Quality of:

- **Roads (including surfaces, road markings, signalling)**
- **Vehicles**
- **Driver training**
- **Driver behaviour**
- **Environmental conditions**
- **Laws and their enforcement**

WHO 2004:

- **In LMICs the majority of deaths are currently among “vulnerable road users” – pedestrians, pedal cyclists and motorcyclists.**
- **Technology transfer from high-income to low-income countries needs to fit local conditions and should address research-based local needs**

Road traffic injuries

Technologies for road traffic injury prevention

Pedestrians & cyclists
- Visibility (reflectors, bicycle lamps, bright cycle helmets)

Motor cyclists
- Crash helmets
- Visibility (Malaysia: most motorcycle crashes were in daytime; c. 2/3 of the riders had the right of way. Motorized two-wheelers that use daytime running lights have a crash rate about 10–29% lower than those that do not.)

Car drivers
- Crash-protective vehicles and roadsides
- Safety fittings (seat belts, air-bags, child restraints)

Law enforcement
- Breathalyzers, speed cameras,
- Speed bumps

e.g. Ghana: rumble strips on main Accra–Kumasi highway at a crash hot spot reduced number of traffic crashes by c. 35%. Fatalities fell by c. 55% and serious injuries by 76%, between January 2000 and April 2001

Process: taking RTI prevention as a 'system'
- Sweden: 'Vision Zero'
- Netherlands: 'Sustainable safety'

Informal transport:
Private buses/minibuses
- Low-cost
- Convenient pickup/drop-off
- Overloaded
- Poorly equipped for safety
- Badly driven
- Poorly regulated

e.g. Nigeria:
molue (locally known as "moving morgues") and *danfo* ("flying coffins")

Mass transport systems
e.g. Bogotá, Colombia:
Construction of TransMilenio mass transport system reduced number of traffic injuries along its routes, with construction of infrastructure to ensure safety of pedestrians and other road users.

http://whqlibdoc.who.int/publications/2004/9241562609.pdf

Road traffic injuries

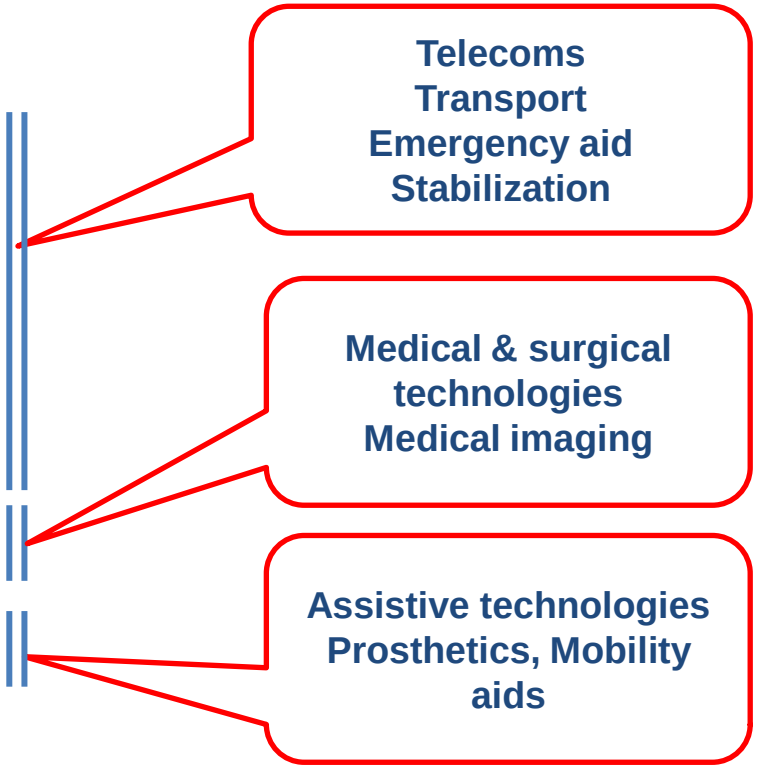
Technologies for road traffic injury trauma management

Proportion of road deaths by setting in three cities

Setting	Kumasi, Ghana (%)	Monterrey, Mexico (%)	Seattle, USA (%)
Pre-hospital	81	72	59
Emergency room	5	21	18
Hospital ward	14	7	23

A chain of critical factors:

- actions, or self-help, at the scene of the crash, by the victims themselves, or more frequently by bystanders
- access to the emergency medical system
- help provided by rescuers of the emergency services
- delivery of medical care before arrival at the hospital
- hospital trauma care
- rehabilitative physical and psychosocial care



http://whqlibdoc.who.int/publications/2004/9241562609.pdf

Technologies for global health
Example 3: Transport and health

Transport-related technologies for health include:

- **Prevention and treatment of road traffic injuries**
- **Ensuring transport for medical emergencies and health-related services**

‘Transport for health’

- **Patient to health care**
- **Health care to patient**
- **Samples for assay**
- **Medicines distribution**

HICs: **Public Transport; ambulances & emergency services; specialized (e.g. refrigerated) vehicles**

LMICs: Some or all of these may be absent

‘Healthy transport’

- **Traveller safety**
- **Clean environment**
- **Health-promoting transport (e.g. supporting exercise)**

Transport for patients and services

eRanger: UK-based NGO

mainly working in sub-Saharan Africa but also with projects in the Caribbean and Asia

Motorcycles - versatile and robust vehicle design: enables access over the toughest terrain to deliver people or cargo safely and in one piece. Construction relatively 'low tech': cost effective, rugged and easy to maintain and repair. Capital and running costs both substantially lower than for car ambulance.

eRanger motorbike & stretcher sidecar

3-wheel motorbike/sidecar fitted for patient transport to and from local health centres/emergency facilities
Cost c. US$ 6,000
e.g. Lowering maternal mortality rates by assisting women in labour to reach birth facilities

eRanger Mobile Immunisation Clinic Unit

Providing primary care interventions to isolated populations: designed for outreach in rural areas.

www.eranger.com

Transport for patients and services

Riders for Health

UK-based NGO working in sub-Saharan Africa

Over 1,400 motorcycles, ambulances and other four-wheel vehicles used in the delivery of health care in 7 African countries.

www.riders.org

Transport for patients and services

ColaLife

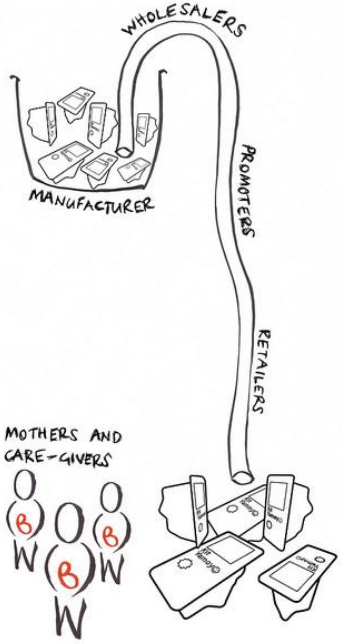
"opening up private sector supply chains for simple medicines"

Issue

- Essential medicines often poorly available in LMICs – especially in remote and rural areas
- Yet Coca-Cola seems to get everywhere in the world

Approach

- Piggy-back on Coca-Cola's highly efficient private sector distribution networks
- Add specially designed transport pod to Coca-Cola crates – fills spaces between bottle necks
- e.g. Recent trial of distribution of 'Yamoyo' anti-diarrhoea kit for children in remote areas of Zambia
  - ORS solution, measure, mixing device, storage device , cup



Technologies for global health
Example 4: Assistive technologies

Sensory aids
- **Vision**
- **Hearing**

Prosthetics
- **Artificial limbs**

Mobility aids
- **Wheelchairs**

Technologies for global health
Example 4: Assistive technologies

Eye glasses

Problem:

WHO estimates > 1.3 billion people worldwide could benefit from eye wear

- Refractive error is greatest cause of low vision globally
- HICs typically 1 optician for every 8,000 people
- LMICs ratio much worse: can be as bad as 1 optician for every 1 million people (e.g. Ghana)
- Mali: 1 optician for every 8 million people

Innovative technology solution: Self-adjustable eye glasses

- Invented by Oxford physics professor Joshua Silver
- Distributed worldwide by Global Vision 2020

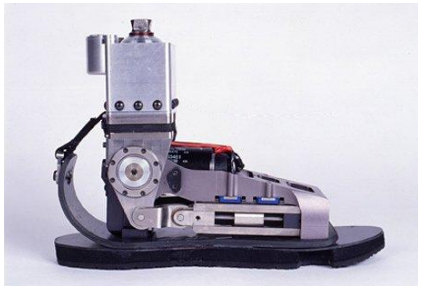
- Each lens consists of a hollow pouch anchored into the frame, into while silicone fluid can be injected from an attached adjuster syringe to change the shape and hence the focal length of the lens.
- Subject adjusts each lens individually until vision in each eye is clear.
- Adjusters removed from eyeglasses and device is ‘set and sealed’ to function like normal glasses.

Technologies for global health
Example 4: Assistive technologies

Prosthetic foot

SACH foot
(Solid Ankle Cushion Heel)
c. US$ 8000

Flex-Foot Assure

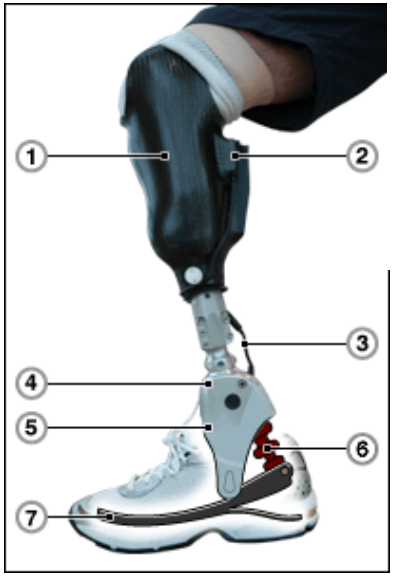


IWalk PowerFoot

Jaipur foot (India): Affordable, versatile prosthetics < US$ 40

Trias prosthetic foot

Flex-Foot Cheetah



'Bionic' lower leg: Up to US$ 100,000

http://oandp.health.usf.edu/Pros/pros_feet/prosthetic_feet.pdf
www.jaipurfoot.org

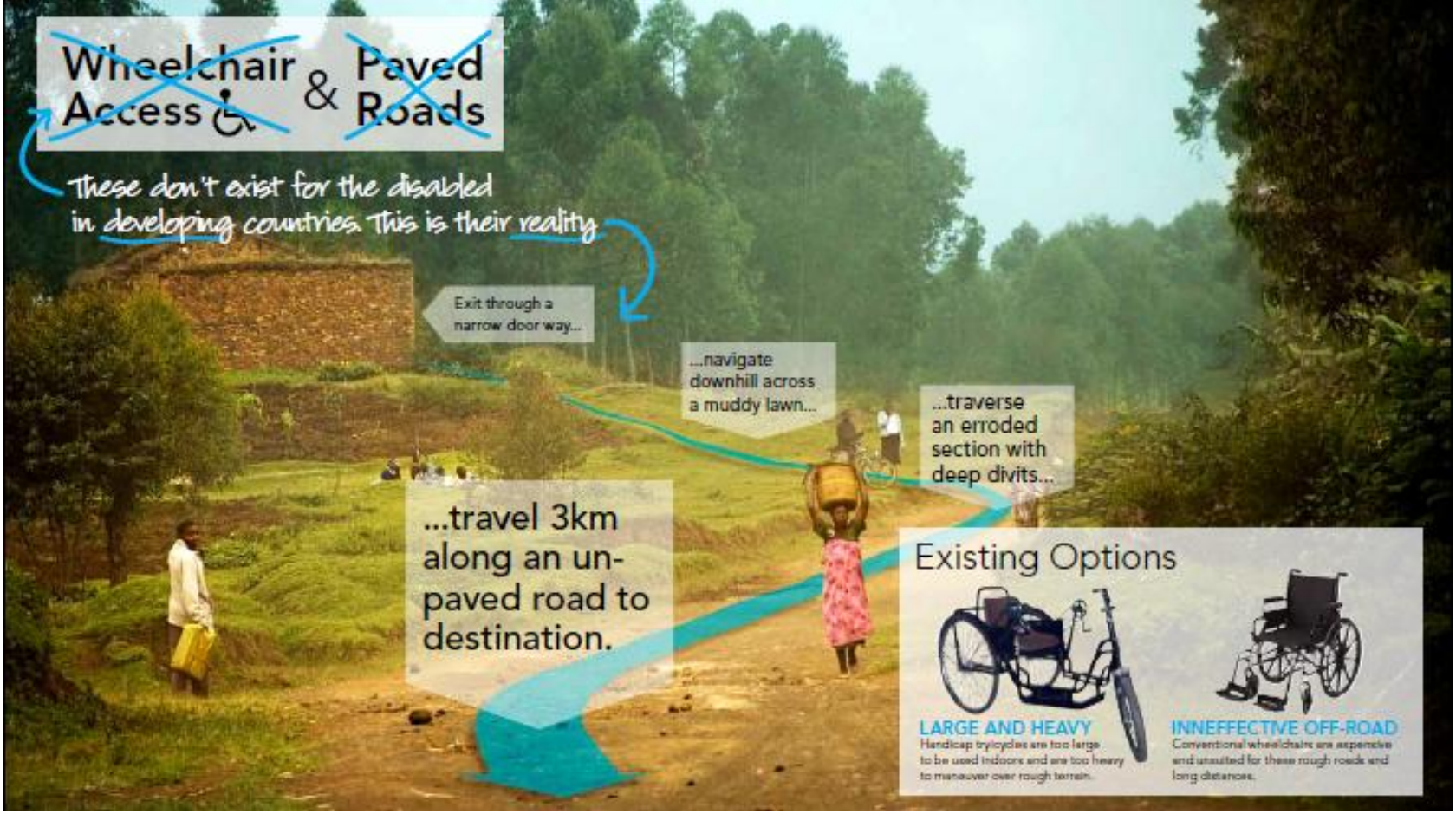
Technologies for global health
Example 4: Assistive technologies

Wheelchair

Basic manual powered £100+

Self-propelled £600+

Vita Midi 4 £3,400



www.dellchallenge.org/sites/default/files/groups/28624/documents/Visual%20of%20conditions.pdf

WHO:

- **1% of the world's population, just over 65 million people, need a wheelchair**
- **In 2008, c. 20 million people in LMICs were in need of a good wheelchair**

- **UN Development Programme:**
- **<1 % of the need for wheelchairs in LMICs is met by local production**

www.who.int/disabilities/publications/technology/wheelchairguidelines/en/index.html
http://whqlibdoc.who.int/publications/2008/9789241547482_eng.pdf

Technologies for global health
Example 4: Assistive technologies

Whirlwind RoughRider

all-terrain wheelchair "for those in developing countries that may not have adequate infrastructure"

Wheelchair

- **Whirlwind: Not-for-profit at San Francisco State University Institute for Civic &Community Engagement: building global franchise network that includes designers, manufacturers, providers/distributors, riders and disability activists.**
- **US$ 800 in USA – c. half other outdoor wheelchairs in USA and 'buy one give one' programme donates one to LMIC for each one purchased in USA.**

Important design features:

- **Wheel base 150% longer than standard wheelchairs: greatly increases stability and safety from forward tipping – No. 1 cause of injury to wheelchair riders**
- **Solid, flexible wide rubber caster wheels eliminate flats and roll easily over grass, mud, rocks, and lightly packed sand.**
- **High traction, puncture-resistant, long wearing rear tires good for off-road travelling**
- **Heavy duty tough frame to prevent broken caster forks and frame failures**
- **Five rear axle positions give 80 mm centre-of-gravity adjustment for optimal balance & ease of pushing**
- **All wearing parts cheaply available virtually and can be installed with basic tools: uses only locally available parts e.g. bicycle wheels and standard bearings from ubiquitous Honda motorcycles**

Guardian 2008: **www.guardian.co.uk/society/2008/apr/07/disabilitysociety**
Whirlwind Roughrider: **www.whirlwindwheelchair.org/roughrider**

Technologies for global health
Example 4: Assistive technologies

Wheelchair

Leveraged Freedom Chair

- low-cost wheelchair designed specifically for rough terrain
- innovation in wheelchair technology created through biomechanics research

- Created by Amos Winter, MIT Mobility Lab
- Simple construction: uses readily available bicycle parts where possible: Costs < US$ 200 to make
- Designed specifically for LMICs. Uses hand-powered leverage enabling user to travel on tarmac faster than a conventional wheelchair and very much easier off-road. Rider can "change gears" by moving hands on the levers – high positions increase torque for rough terrain, low positions increase angular velocity for fast travel on smooth terrain.
- Being prepared for production in partnership with India's Jaipur Foot - aiming to design manufacturing tools necessary for high volume production: minimum 500 units/month. 1st pilot production in 2012

Amos Winter: 'Ted Talks'

www.ted.com/talks/amos_winter_the_cheap_all_terrain_wheelchair.html

www.dellchallenge.org/projects/leveraged-freedom-chair
http://web.mit.edu/newsoffice/2010/amos-wheelchair-0218.html

Technologies for global health
Example 5: Medical & surgical technologies

Innovative *products*

Innovative *processes*

Medical & surgical technologies

Innovative *products*

Syringes

Simple medical syringe with needle
- Glass or plastic plunger and tube, various sizes
- Separate needle, various lengths and tip profiles
- Usually supplied separately in sterile packaging

Advantages
- Cheap, simple
- Reusable (glass) or disposable (plastic)
- High degree of flexibility for different applications
- Can be supplied pre-loaded with fixed volume of specific product

Problems
- Patient safety: potential for re-use without proper sterilization
- Health worker safety: potential for scratch and prick injuries
- Public safety: potential for misuse (injecting substance abusers) and accidental injuries/poisoning if proper disposal not organized (storage, collection and destruction of chemical and biological hazards and sharps)

Medical & surgical technologies

Innovative *products*

Syringes for safe injections: WHO - four types currently used around the globe

Group 1: Reuse Prevention Feature

Auto-disposable (AD) syringes are designed to prevent reuse by patients and health care workers. After being utilized once, the syringes are put out of action due to an internal mechanism which blocks the plunger once it is fully pressed.

Breaking Plunger syringes contain the same purpose and a similar functioning as the AD syringes. Once the plunger is fully pressed, an internal mechanism cracks it completely, impeding any possibility of reuse.

www.who.int/eht/ps/en/index.html

Medical & surgical technologies

Innovative *products*

Syringes for safe injections: WHO - four types currently used around the globe

Group 2: Reuse and Needle Stick Prevention Features

Needle Stick Prevention syringes, apart from having a mechanism to avoid reuse, also protect health care workers and patients from needle related injuries and infections. The syringes contain a shield, made either of paperboard or plastic, which covers the needle creating a protective cap.

Retractable syringes, apart from preventing reuse and needle sticks, also avoid hazardous sharps waste. After being used, the needle is pulled back inside the syringe barrel upon retraction of the plunger.

www.who.int/eht/ps/en/index.html

Medical & surgical technologies

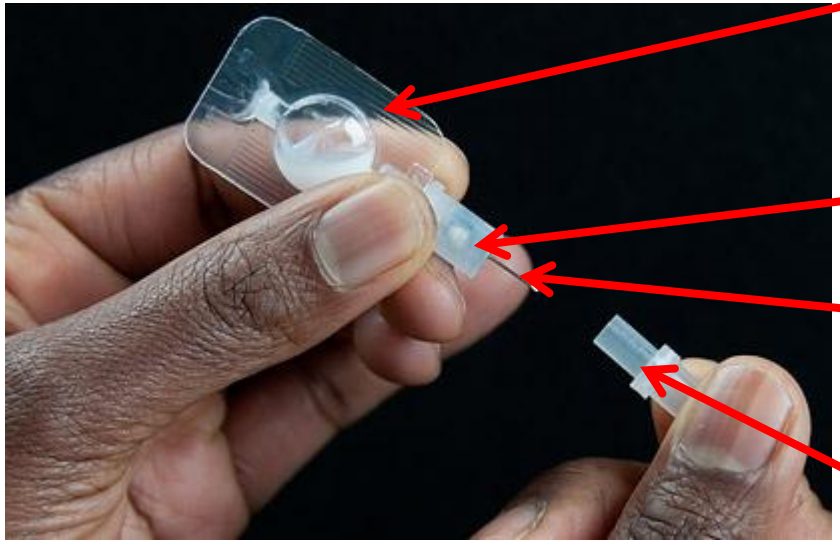
Innovative *products*

Safe injections in poor resource settings

Program for Appropriate Technology in Health

- **International NGO established in Seattle in 1977: focus on health technologies for LMICs**
- **Works on a range of health technologies, including diagnostics, nutrition, safe birth and newborn health, safe water, vaccines, safe injections**

Uniject pre-filled injection system



Pre-filled plastic pouch contains fixed dose of injectable agent – 1 press only

One-way valve prevents re-filling for multiple use

Manufactured with different needle lengths for different applications (short here for sub-cutaneous)

Needle cover protects

Medical & surgical technologies

Innovative *products*

Safe injections in poor resource settings

Applications of Uniject pre-filled injection system:

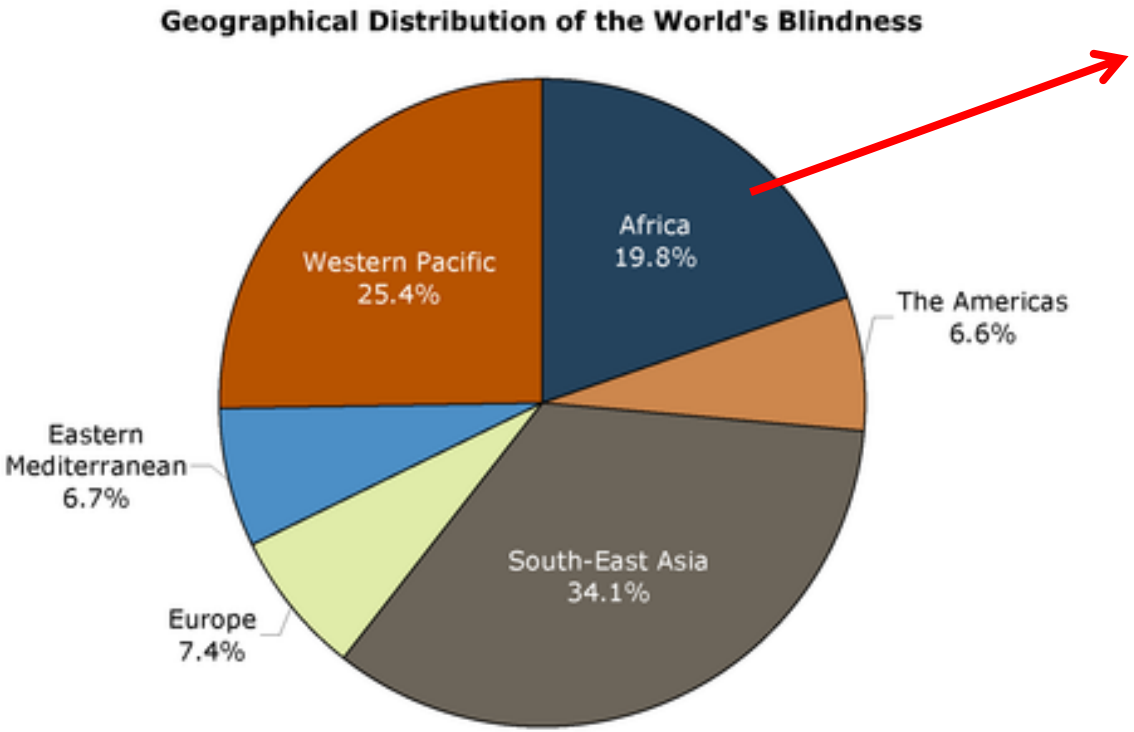
- **Gentamcin – treatment of serious bacterial infections in the new-born**
- **Oxytocin – reducing uterine bleeding following childbirth**
- **Vaccines – tetanus, hepatitis B**
- **Contraception – long-acting injectable hormonal contraception for women**

Technologies for global health
Example 5: Medical & surgical technologies

Innovative *processes*

Problem:

Large amount of avoidable blindness in LMICs. One major cause is cataracts, requiring eye surgery. Often unavailable or unaffordable in public health systems in LMICs.



WHO:

50%	cataract
15%	glaucoma
10%	corneal opacities
6.8%	trachoma
5.3%	childhood blindness
4%	onchocerciasis

www.cureblindness.org/world-blindness/

Technologies for global health
Example 5: Medical & surgical technologies

Innovative *processes*

Innovative solution in India: Aravind Eye Care Hospital

- 1976 First hospital founded by Dr. Govindappa Venkataswamy.
  - Alternate health care model: supplement government efforts and also be self-supporting.
  - Started with 11-bed hospital in his brother's home at Madurai after most banks refused to lend him money . 6 beds reserved for people who could not afford to pay; the remaining 5 for paying patients.

- Now a network of eye hospitals treating a range of eye conditions using state-of-art equipment for diagnosis and treatment.
  - Seen total of nearly 32 million patients in 36 years;
  - Performed nearly 4 million eye surgeries, majority very cheap or free, subsidised by those who can afford to pay:
  - Now conducting nearly 7% of all eye surgeries in the world.

- Apart from financial innovation, key step was to develop high-throughput, high-efficiency processes.
  - e.g. doctors sit between 2 operating tables; when finished with one, they turn to the other patient, already draped and ready - saves valuable time between surgeries.
  - So surgeons extremely productive; pushed down average cost of surgery. In year ending March 2012, Aravind had over 2.8 million outpatient visits and over 340,000 surgeries performed. Aravind's surgeons conduct average 2,000 operations/ year: number in USA is just 125.
  - High number of surgeries does not mean more mistakes or compromise on quality. The number of complications at Arvind are nearly half of those in the British Health System for the same procedures.

- Experiencing rising costs and availability of intraocular lenses, Aravind started Aurolab in 1992: on-site lens manufacturing facility. Aurolab now produces nearly 1.8 million lenses for a price as low as US$ 2.

www.aravind.org

Technologies for global health
Example 5: Medical & surgical technologies

Innovative *processes*

Problem

India needs 2.5 million heart operations a year but does only 90,000.

Heart surgery: Narayana Hrudayalaya (NH) Hospitals, India

"making the industry more efficient by applying Henry Ford's management principles".

- **2000: started by Dr. Devi Prasad Shetty**
  - **Believes combination of economies of scale + specialisation can radically reduce heart surgery cost**
- **First NH hospital in Bengaluru: now one of India's largest multi-specialty hospital chains with strong specialization in cardiac surgery.**
- **Bengaluru Health City hospital complex, completed in 2012, includes the world's largest heart hospital with 1000 beds: 40+ cardiologists performing c. 600 operations per week; as well as a full-fledged 1400-bedded multi-specialty hospital that handles neurosurgery. Also receives patients from outside India and has created a record of performing nearly 15,000 surgeries on patients from 25 foreign countries.**
  - **Large number of patients allows surgeons to acquire world-class expertise in particular operations, and generous backup facilities allow them to concentrate on their speciality rather than wasting time on administration. Shetty has performed >15,000 heart operations and other members of his team >10,000. NH performs c. 24 open heart surgeries and 35 catheterization procedures a day, c. 8x the average at other Indian hospitals.**
  - **In cardiology, the hospital specialises in Interventional Cardiology, Electrophysiology and Pediatric Cardiology, and also performs cardiac surgeries like Coronary Artery Bypass Grafting, Redo Coronary Artery Bypass Grafting. Total of 15,000 coronary bypass grafting operations have been performed in the Bengaluru hospital alone.**
- **NH also has 17 linked Coronary Care units based in remote cardiac hospitals. These units handle emergency cardiac-related cases and the patients are controlled and stabilised before the cardiac specialists are consulted. NH also runs postgraduate programmes for doctors and other medical staff on heartcare and also offers India's only formal training programme for pediatric cardiac surgery.**

Technologies for global health
Example 5: Medical & surgical technologies

Innovative *processes*

Heart surgery: Narayana Hrudayalaya Hospitals, India

- NH charges an average of US$2,000 for open-heart surgery, compared with US$20,000-100,000 in USA, but its success rates are as good as in the best US hospitals. Also acts as a philanthropist by charging less than the normal cost for procedures like angiogram and cardiac surgery to people who cannot afford to pay. Despite helping so many poor patients, it is known for being so efficient that it has a higher profit margin (7.7% after tax) than most American private hospitals (6.9%).
- NH has established video and internet links with hospitals in India, Africa and Malaysia so that its surgeons can give expert advice to less experienced colleagues. Also sends "clinics on wheels" to nearby rural hospitals to test for heart disease.
- Shetty has created a health-insurance scheme that covers 2.5m people for a premium of 10-15 cents a month each. About a third of the hospital's patients are now enrolled in the scheme. A sliding scale of fees is used for operations so that richer customers subsidise poorer ones.
- The group has recently built three other hospitals next to the heart clinic—a trauma centre, a 1,400-bed cancer hospital and a 300-bed eye hospital. They all share central facilities such as laboratories and a blood bank. Dr Shetty is also setting up "medical cities" in other parts of the country. Over the next 5 years his company plans to increase its number of beds to 30,000, making it the largest private-hospital group in India and giving it more bargaining power when it negotiates with suppliers, thus driving down costs further. NH dental clinics were started in 2008 and plans to expand to 300 centres by 2015.
- UK doctors being sent to NH for training:
  - Shetty is scathing about Western restrictions on doctors' working hours. "By the time you're an experienced surgeon, it's time to retire. Any cardiac surgeon of substance has worked long hours."
  - "While hospital admission remains 10 times riskier than sky diving, healthcare needs more process innovation rather than product innovation."

www.narayanahospitals.com
www.economist.com/node/15879359
www.narayanahospitals.com/about-us/media-room/news-updates/?newsid=28

Technologies for global health
Example 6: Medical imaging

Up to 2010, a total of c. 5 billion medical imaging studies had been done worldwide; 2/3 employ ionizing radiation (X, ɣ)

Key imaging technologies for medical diagnostics

Ionizing
- **X rays**
- **Computed axial tomography (CAT)**
- **Positron emission tomography (PET)**

Non-ionizing
- **Magnetic resonance imaging (MRI)**
- **Ultrasound**

HICs: **Readily available – but often expensive and often over-used**

LMICs: Poor or no availability

- **Japan has 90x as many MRI scanners/person as India**

Ultrasound

Toshiba Nemio 10

Mindray Z6 portable, with probes

In UK:
‘Top-end’ scanners £20,000 – 60,000
‘Low-end’ scanners £5,000

Ultrasound

2010: University of Washington undergraduate students won Gates Foundation Grant: Low-cost ultrasound system for scanning pregnant women

- **ultrasound probe connects via a USB port to a netbook with a touch-sensitive screen**
- **designed to be cheap, portable, durable and easy to use.**
- **cost c. US$ 3,500**
- **testing planned in USA, Uganda**

www.eurekalert.org/pub_releases/2010-11/uow-ulu110910.php

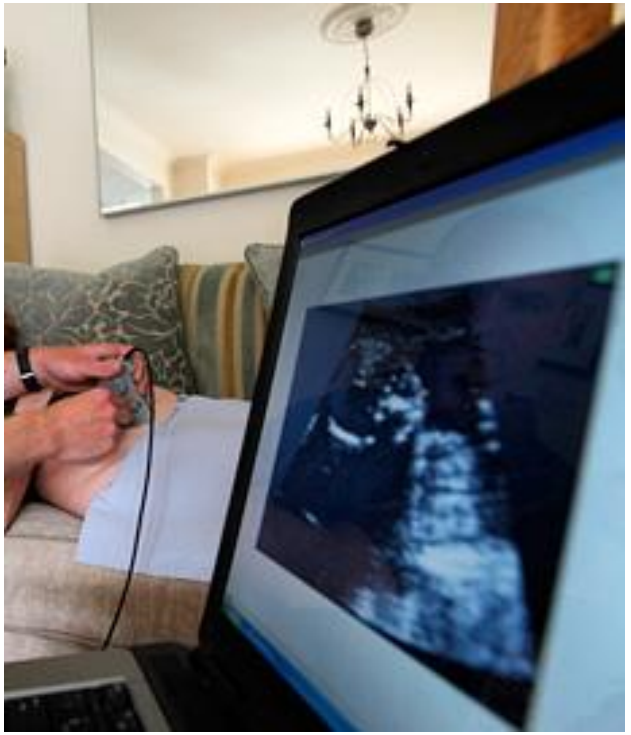
Ultrasound

2012: Jeff Neasham & Dave Graham, Newcastle University

- Neasham an expert in underwater sonar technology:
  - Original aim to make something portable and easy to use that would be affordable in LMICs as well as for some applications in UK where ultrasound is still considered cost prohibitive
  - Goal: a device that could be produced for a similar cost to the hand-held Doppler devices (foetal heart monitors) used by most community midwives

Ultra-low cost scanner, can be plugged into any computer to show images of an unborn baby

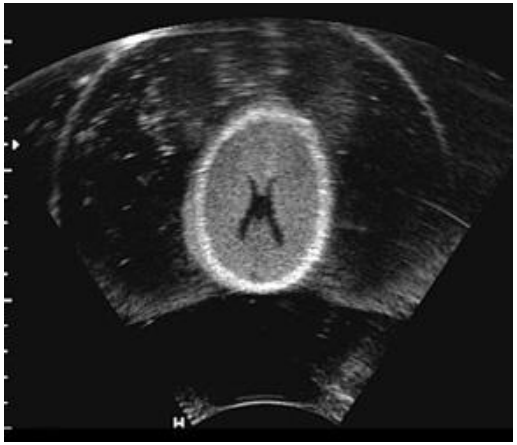
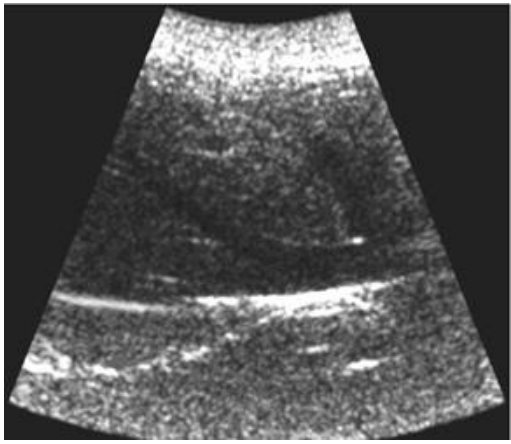
- Hand-held USB device roughly the size of a computer mouse
- Cost: £30-40
- Output power 1-10% of conventional scanners
- Should facilitate rapid, cheap antenatal screening in LMICs
- Potential for major impact on ultrasound applications in HICs



www.ncl.ac.uk/press.office/press.release/item/low-cost-design-makes-ultrasound-imaging-affordable-to-the-world#.UMHUiKxhHFIhtm

www.ncl.ac.uk/business/commercialisation/transfer/biomedical-sciences/ultrasound.

Ultrasound

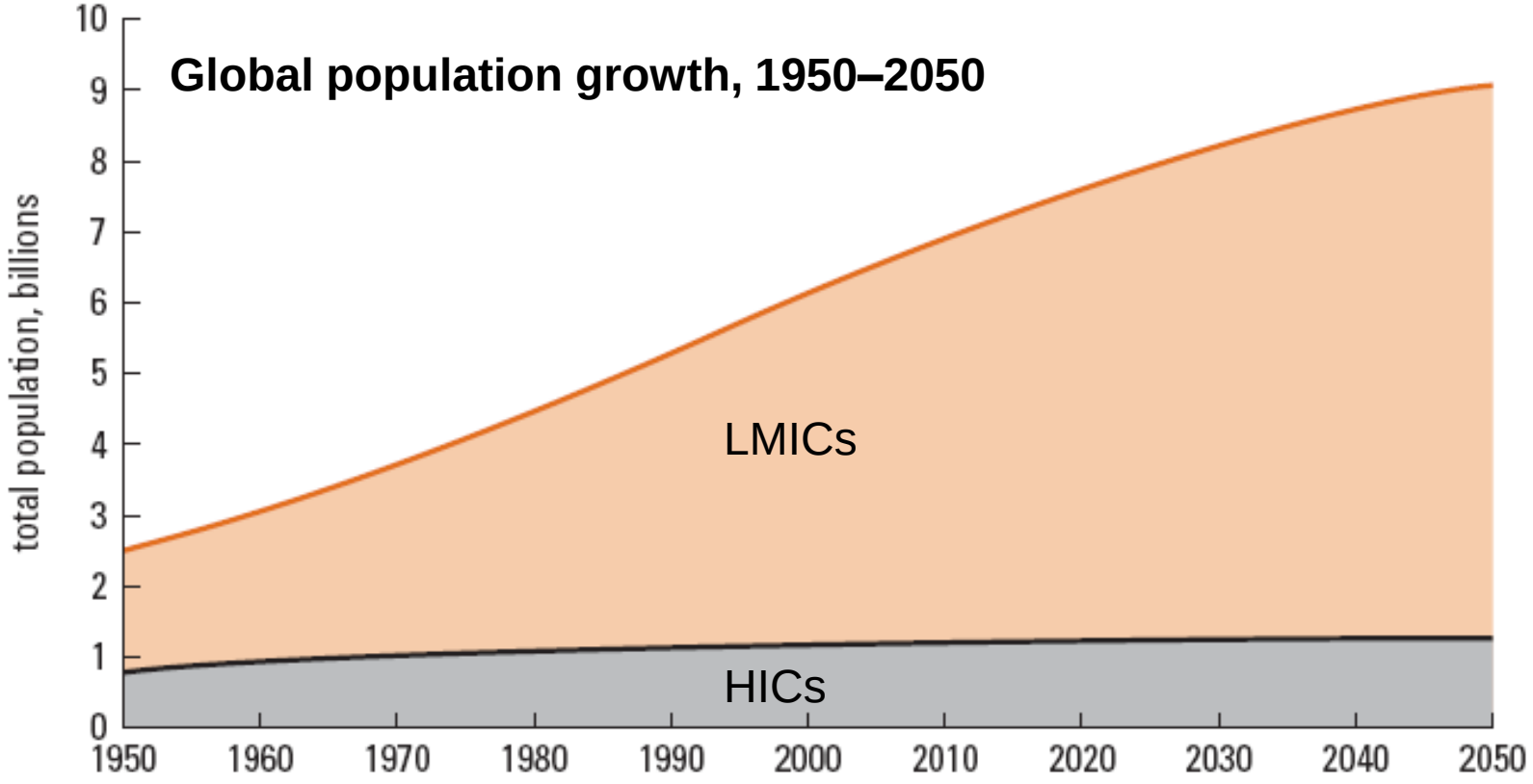
	Cross section of head showing ventricles	Profile of face and head	Human liver and hepatic veins
Images from £50,000-£100,000 device			
Images from Newcastle's low cost device			

Technologies for global health
Example 7: Water

Increasing population
Climate change

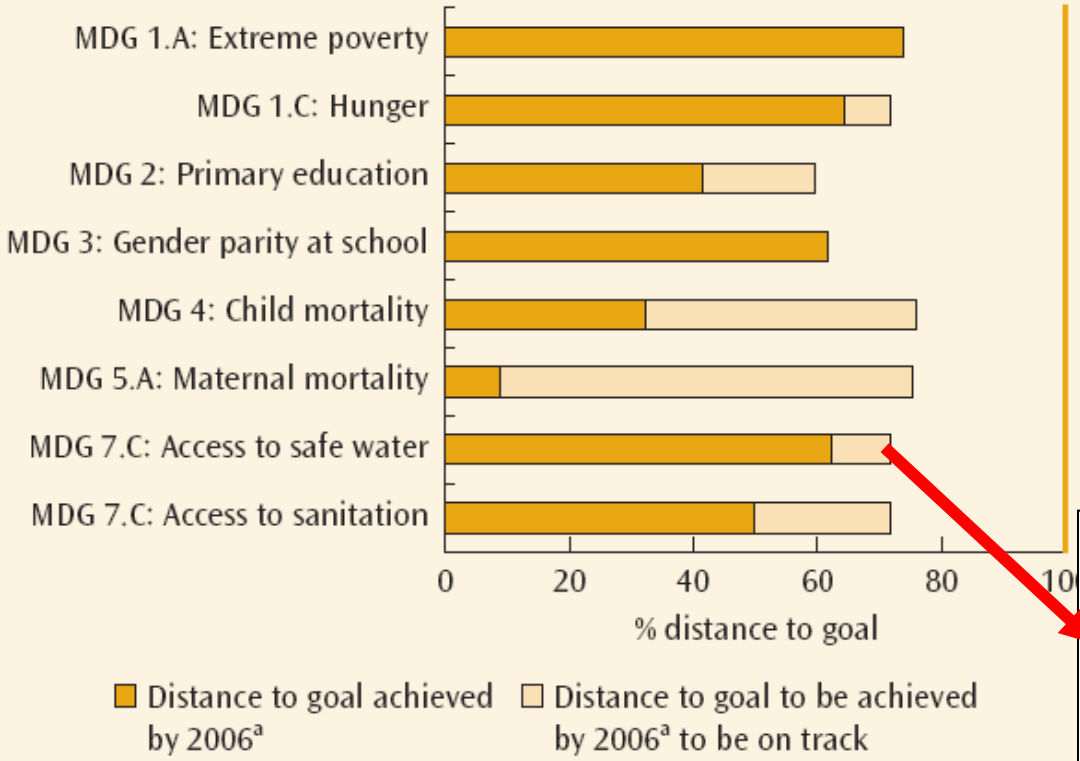
→ Increasing demand for water for agriculture and domestic use

Changing demographics

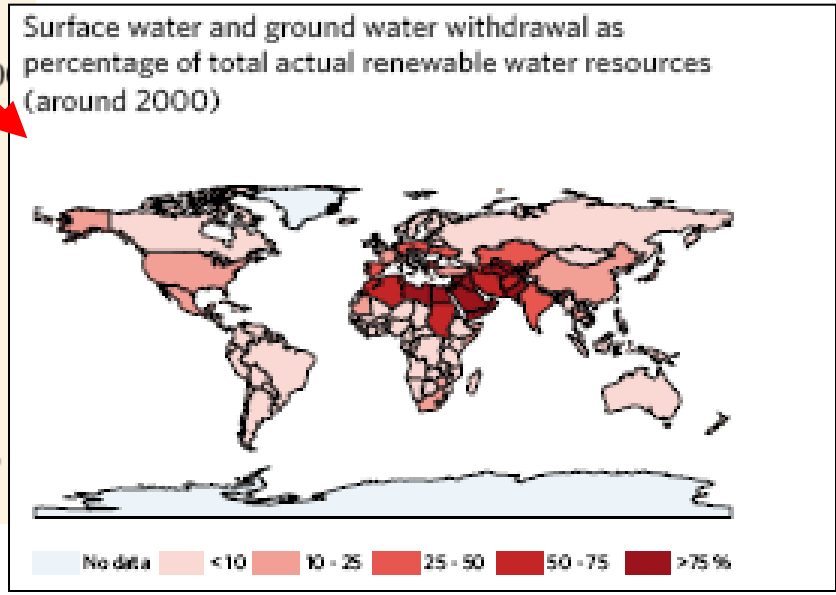


Health Financing Revisited: A Practioner's Guide. P Gottret, G Schieber, World Bank, 2006

FIGURE 1 At the global level, progress and prospects vary widely across MDGs



Source: Staff calculations based on World Development Indicators.
a. Most recent year for which data are available.
Notes: MDG 1.A: Poverty headcount ratio (PPP93 US$1.08 a day); MDG 1.C: Underweight under-five children (U.S. child growth standards); MDG 2: Primary education completion rate; MDG 3: Gender parity in primary and secondary education; MDG 4: Under-five mortality rate; MDG 5.A: Maternal mortality ratio (modeled estimates); MDG 7.C: Access to improved water source; MDG 7.C: access to improved sanitation facilities.



Global Monitoring Report, *World Bank 2008*

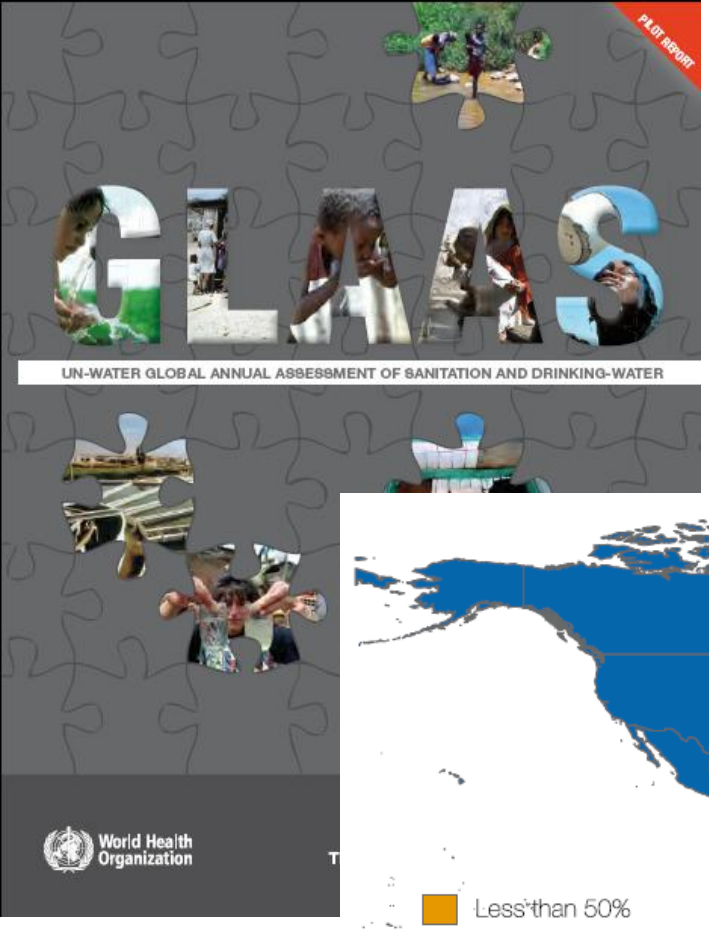
c. 2.8 billion people (>40 % of the world's population) live with some form of water scarcity.

The Millennium Development Goals Report. UN 2008

Water

Millennium Development Goal Target 7.C:

- **Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation**



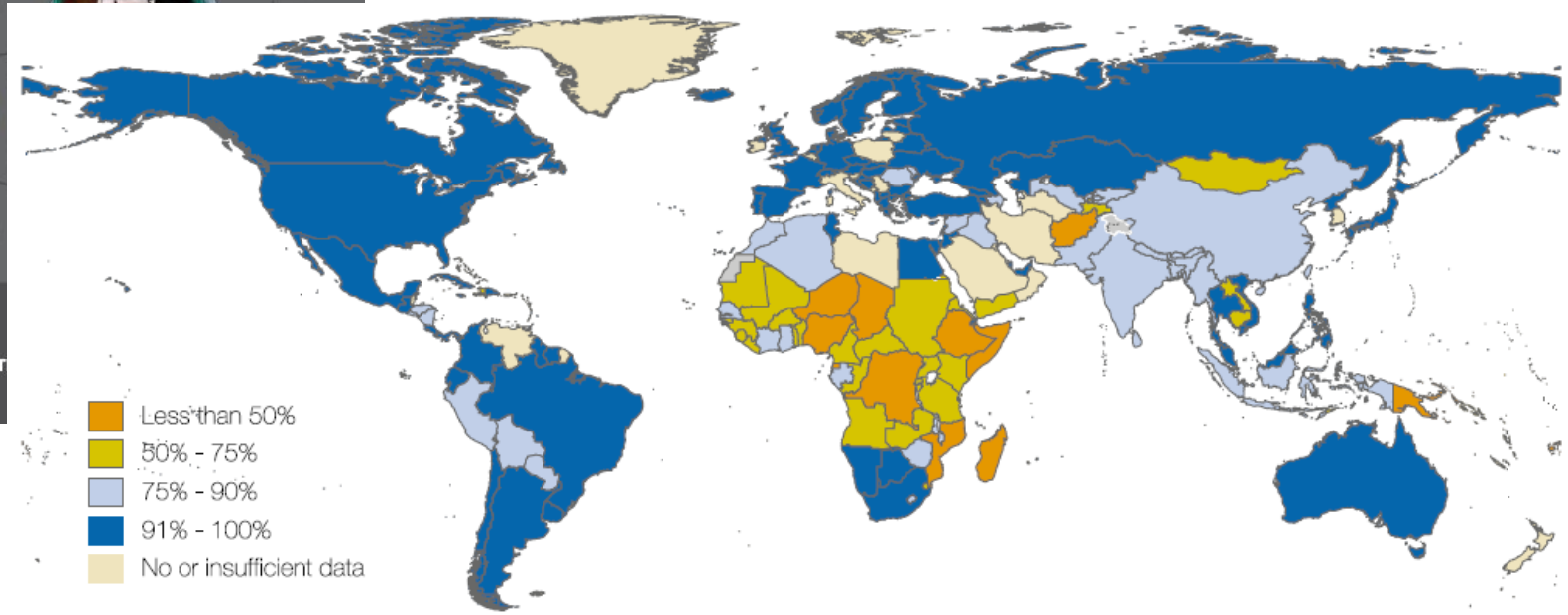
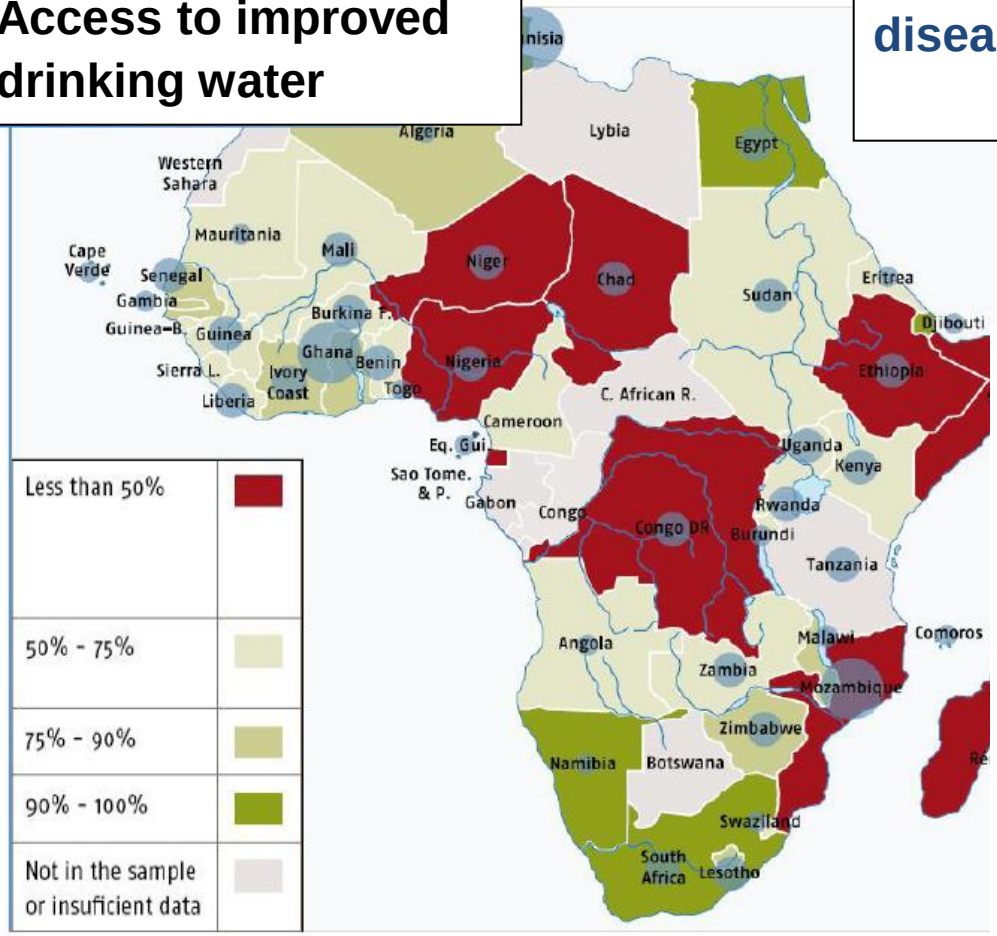


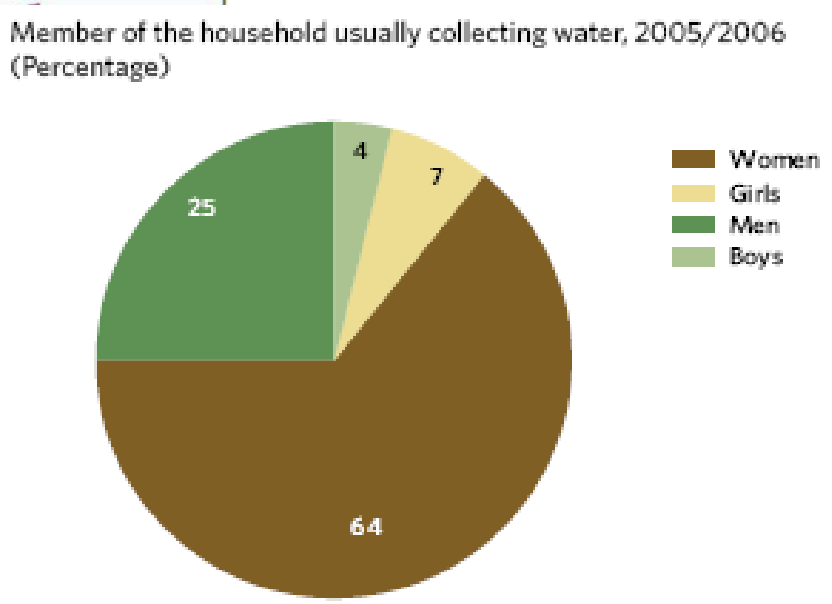
FIGURE 2: Improved drinking-water coverage, 2006

UN-Water Global Annual Assessment of Sanitation and Drinking-Water (GLAAS), WHO, 2008
www.who.int/water_sanitation_health/glaas_2008_pilot_finalreport.pdf

Access to improved drinking water

2 m deaths every year from water-related diseases: mostly children < age 5





Though access to improved drinking water has expanded, nearly one billion people do without

The Millennium Development Goals Report. UN 2008

Recent findings confirm anecdotal evidence that women shoulder the bulk of responsibility for collecting water when none is available on the premises.

Technologies for global health
Example 7: Water

Large-scale solution

- **Identify sustainable sources of water**
- **Purify as necessary to make the water fit for drinking**
- **Pipe to every location where significant numbers of people live**

Technologies for global health
Example 7: Water

Tata Swach

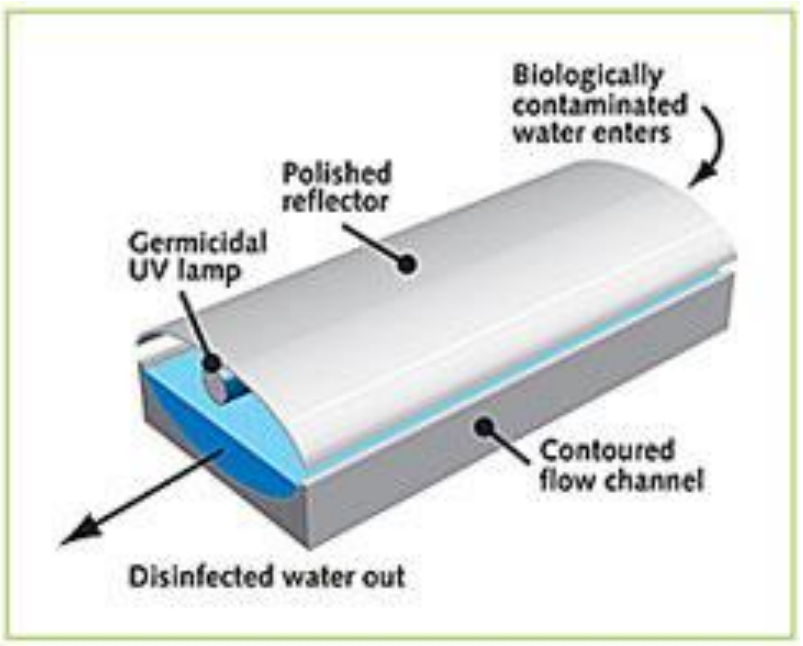
Nanotech purification technology

- Water purification carried out using processed rice husk ash impregnated with nano silver particles: filters the water and destroys disease-causing organisms.
  - Bacteriostatic and bactericidal properties of silver attributed to its ability to react with the sulfhydryl (-SH) groups in the bacterial cells.
  - Nano-sized particles help in increasing the surface area so that the bacteria get enough reaction time
- Can purify water at the rate of about 3 to 4 litres/hour
- Purifier consists of 2 parts; upper reservoir where untreated water enters and a lower middle portion with a bulb to which the cartridge can be attached.
- The 2 chambers stackable and arranged so that the entire system can function on gravity.
- Tata Swach Smart and Smart Magic are variants with a more compact design, holding 15 and 7 litres respectively.
- Purifies a litre of water at a cost of 10 paise (100 paise =1rupee; approx Rs45 = US$1).

www.tatachemicals.com/products/tata_swach.htm#.UMJGyaxhHFI

Technologies for global health
Example 7: Water

UV Waterworks™



Provides affordable and safe drinking water to about 600,000 people daily

www.waterhealth.com/water-solutions/technology.php

Solar water disinfection (Sodis)

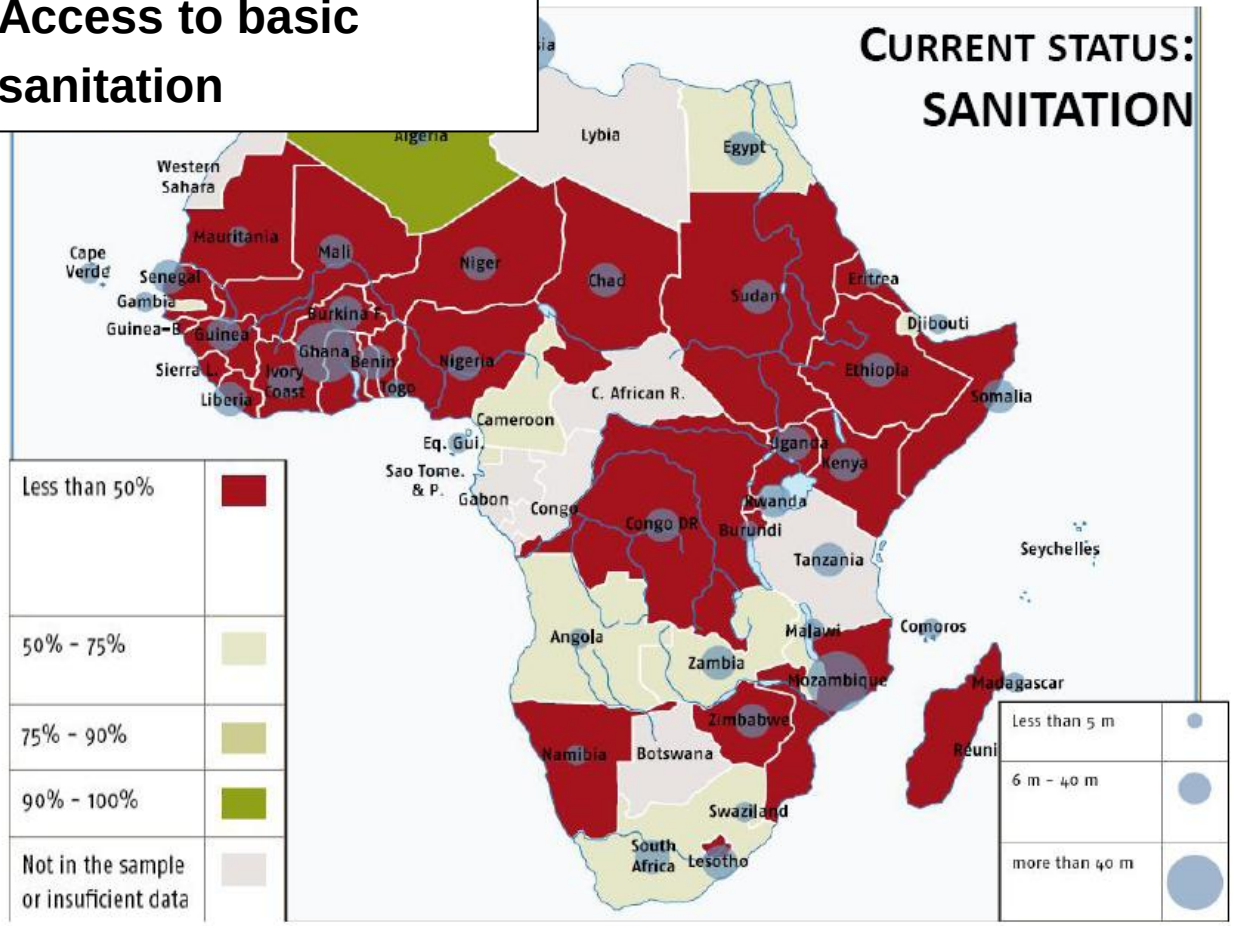
Even cheaper alternative

- **already in use in 20 countries**
- **radiation from sunlight cleans water in clear plastic PET bottles, by shaking and then leaving in the sun for at least 6 h**

www.sodis.ch

Technologies for global health
Example 8: Sanitation

Access to basic sanitation

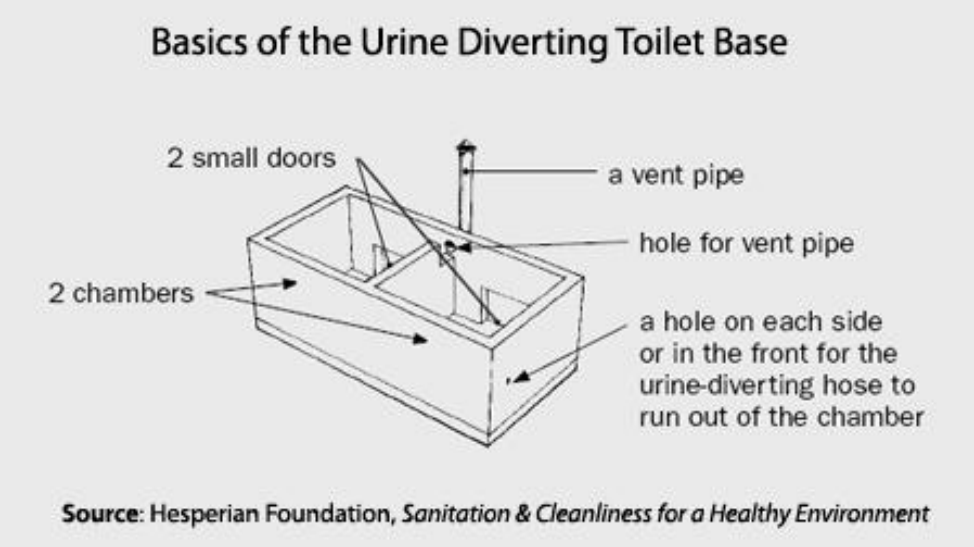


Large-scale solution

- **building large-scale infrastructures for the collection, transport and treatment of sewage.**

Technologies for global health
Example 8: Sanitation

Basic technologies



Urine-diverting dry toilets offer a safe and sanitary way to deal with fecal material, can be permanently sited as opposed to pit latrines, and don't require water. The dry conditions kill most pathogens and parasites, including roundworm eggs.

www.aidg.org/component/option,com_jd-wp/Itemid,34/p,1044/

Social innovation

Subsidy or self-respect? 'Participatory total community sanitation' in Bangladesh

- **Community empowerment for '100% sanitation' – now implemented in >100 villages in Bangladesh**
- **>20 new low-cost models of toilet emerged**

www.id21.org/insights/insights45

Technologies for global health
Example 9: Health-promoting/sustaining shelter

Household air pollution (HAP)

The issue

- c. 3 billion people (nearly half world's population) cook their food and heat their homes by burning coal and biomass, including wood, dung, and crop residues, in open fires or rudimentary stoves.
- Indoor burning of solid fuels releases dangerous particulate matter, carbon monoxide, and other toxic pollutants, and releases greenhouse gases into the air.
- The resulting indoor air pollution levels are 20 to 100 times greater than WHO air quality guidelines allow.

Current scale of the problem: GBD2010

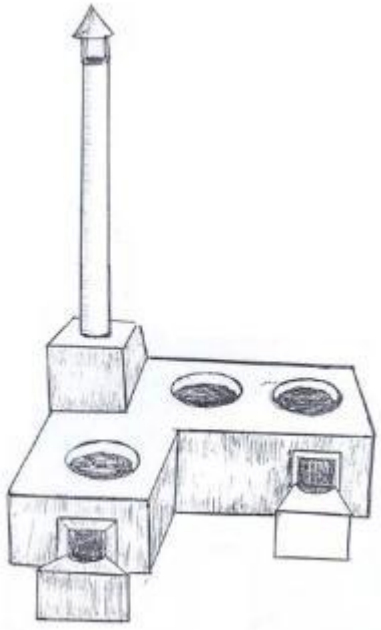
- 3.5 million direct premature deaths annually in 2010 from HAP
  - 0.5 million of the total are child pneumonia deaths
  - Rest are adult deaths (men and women) from lung cancer, cardiovascular disease (CVD), and COPD. Cataracts are also included, but they cause very few deaths.
- In terms of absolute impacts, men are more affected than women.
  - Counterintuitive result: because men have so much higher background rates of the major diseases. Thus, although women have higher exposures and higher elevations in risk for these diseases, men end up with the larger burden.
- In relative terms, women are more affected by HAP.
  - In terms of DALYs, HAP is 2nd most important risk factor for women and girls globally among those examined; 5th for men and boys. 1st for both sexes in South Asia and for women and girls in most of Sub-Saharan Africa. 6th for both sexes in East Asia.
- Most important single environmental risk factor globally and in poor regions. Behind outdoor air pollution (OAP) in richer countries, of course, and in China, where OAP ranks fourth among all risk factors examined.
- 2.8 billion people rely on solid fuels for their main cooking fuel in 2010, a number that seems to have been roughly stable globally for the last decade or so. This is more people than anytime in human history relying on solid fuels for cooking.

Technologies for global health
Example 9: Health-promoting/sustaining shelter

Cooking stoves for clean indoor air: combating household air pollution (HAP)

2-pronged approach:

- **Better fuels**
- **Better design of stoves**
  - **Burn fuels more efficiently and completely**
  - **Exhaust gases through stovepipe**



Chulha stove

- **Bangladesh**
- **Originally clay, now concrete**
- **New variations of the Chulha have emerged to address different fuel types. Originally designed to use all biomass but does not always perform optimally for each. Small modifications can be made to the combustion chamber to improve the efficiency with different forms of biomass.**

www.cleancookstoves.org/resources_files/bangladesh-market-assessment-mapping.pdf

See:
Global Alliance for Clean Cookstoves
www.cleancookstoves.org

Key reading...

The Lancet Commissions

Imperial College London

THE LANCET

Technologies for global health

Peter Howitt, Ara Darzi, Guang-Zhong Yang, Hutan Ashrafian, Rifat Atun, James Barlow, Alex Blakemore, Anthony M J Bull, Josip Car, Lesong Conteh, Graham S Cooke, Nathan Ford, Simon A J Gregson, Karen Kerr, Dominic King, Myutan Kulendran, Robert A Malkin, Azeem Majeed, Stephen Matlin, Robert Merrifield, Hugh A Penfold, Steven D Reid, Peter C Smith, Molly M Stevens, Michael R Templeton, Charles Vincent, Elizabeth Wilson

Executive summary

Availability of health technology is inversely related to health need. Although health-care systems in high-income countries make extensive use of technology, people in the world's poorest countries often lack the most fundamental drugs and devices. A concerted global effort to encourage the development and use of health technologies that can benefit the poorest people in the world is needed.

Technologies for global health refers to a broad category of interventions that reduce malnutrition, careful consideration given to achievement of successful implementation and scale-up, requiring a focus not only on technology but also on associated process innovations that enable effective use. Introduction and use of technology in resource-poor settings raises several issues that need to be addressed. How can technology be ensured to improve rather than damage health? And how should technology be deployed in an equitable, but financially sustainable way? Additionally, greater focus on frugal technology offers truly global promise. Novel technologies are being created in low-income and

Lancet 2012; 380: 507–35

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See Editorial page 447

See Online for a video interview with Peter Howitt

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