Democratizing Energy Technology

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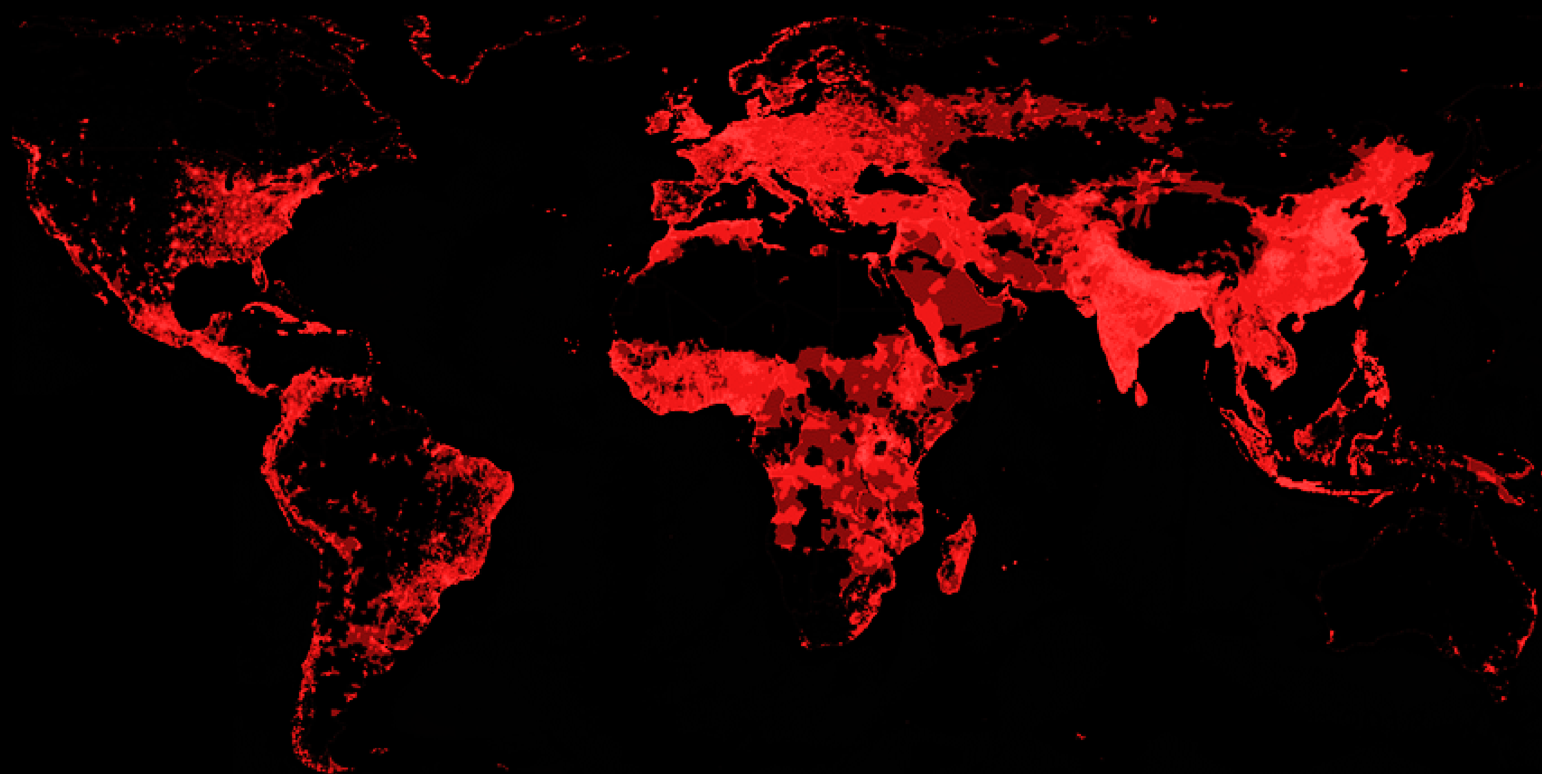
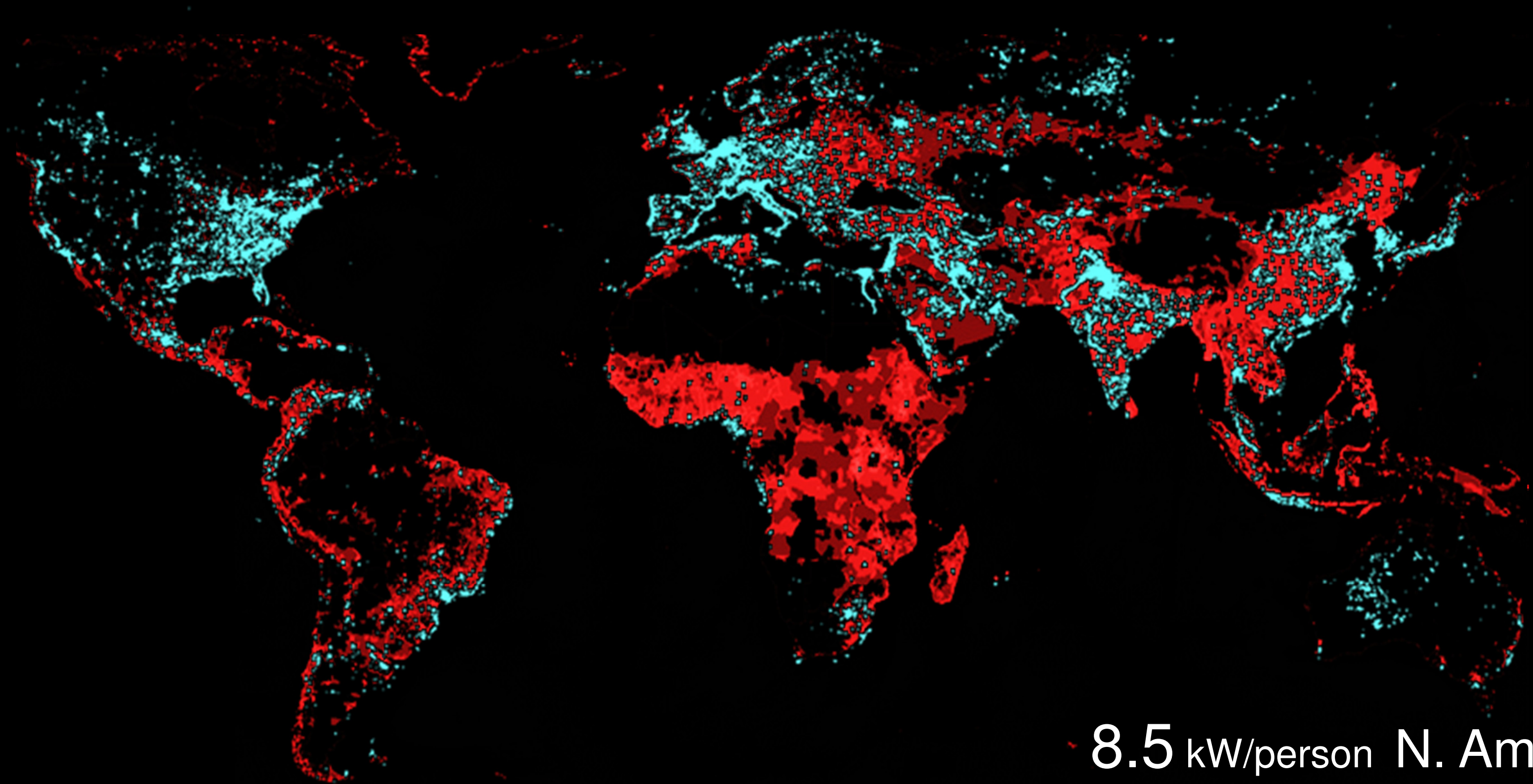
EARTH AT NIGHT

WORLD POPULATION DENSITY



POPULATION AND ENERGY USE



8.5 kW/person N. America
0.5 kW/person Africa

Isaac Mkalia, 20, checks his mobile phone in Kojiado district, near the Tanzanian border (Photograph: Sven Torfinn/Oxfam)

Technologies that Democratized the World

1450

Gütenburg Press

INFORMATION

1908

Ford Model T

TRANSPORTATION

1950

ISO Shipping Container

SHIPPING

1973

Motorola DynaTAC 8000X

COMMUNICATION

1977

Commodore PET

COMPUTATION

Democratizing Technology

WHAT ARE THE DEFINING FEATURES?

1. Empowers the little guy
2. Never developed by the incumbent
3. Displaces entrenched incumbent
4. Levels the playing field
5. Leverages capital of the many
6. Modular, mass produced, standardized
7. Fast innovation cycles

…and there are many examples

guns	*…displaced*	*swords*
Gutenberg press	*…displaced*	*illuminated manuscripts*
iso-containers	*…displaced*	*bulk shipping*
cellular phones	*…displaced*	*land lines*
personal computers	*…displaced*	*central computing*
automobiles	*…displaced*	*horses*
photovoltaics	*…displaced*	*solar thermal*
electric-arc furnaces	*…displaced*	*blast furnaces*
internet	*…displaced*	*store fronts*
televisions	*…displaced*	*theatres*
record players	*…displaced*	*live musicians*

What about energy technology?

Energy Technology Today

PRICE TAG
$1-10 BN

COAL POWER PLANT

PRICE TAG
$0.5-5 BN

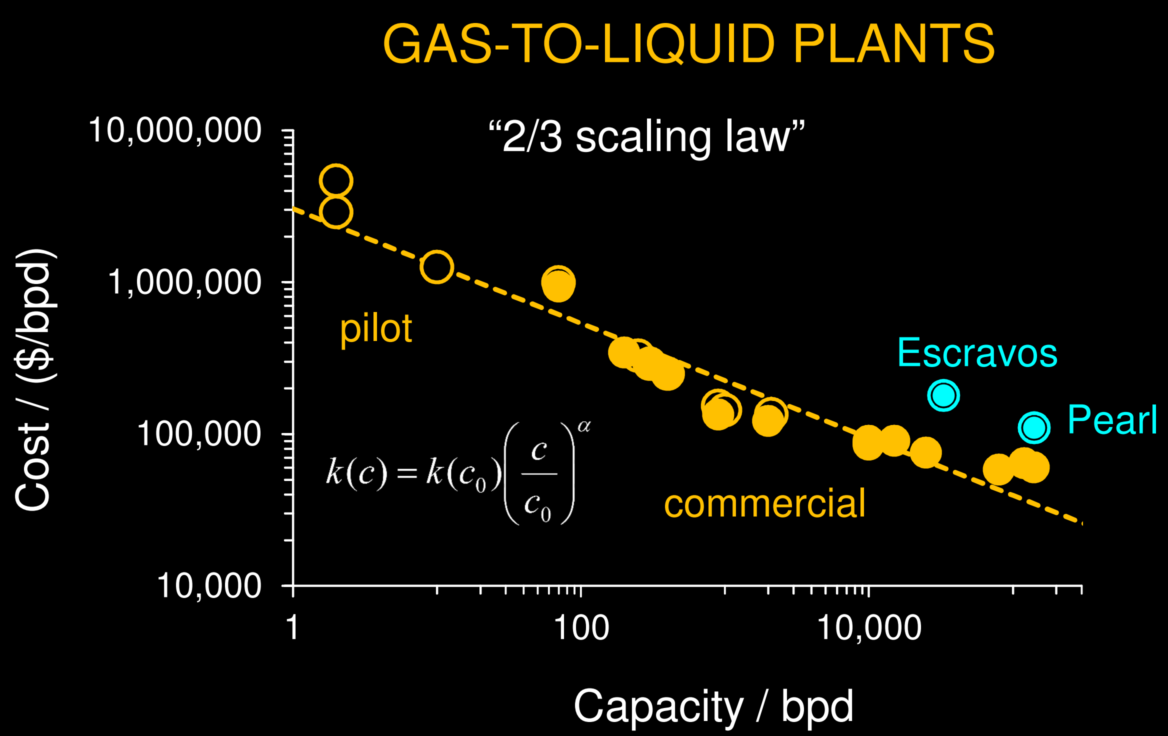
AMMONIA PLANT

PRICE TAG
$5-50 BN

GTL PLANT

Why do we go big?

Economies of Unit Scale

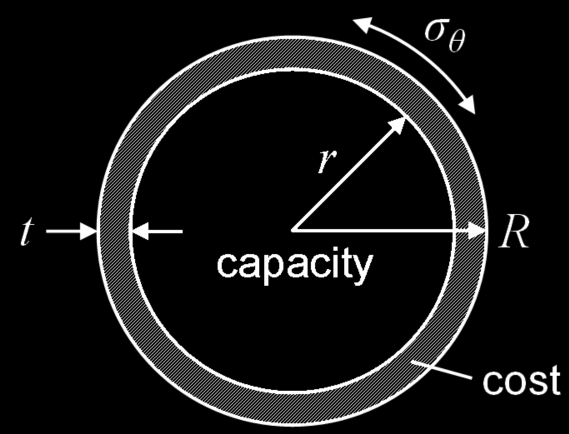


Sources: (1) PJA Tijm. Gas to liquids, Fischer-Tropsch, advanced energy technology, future's pathway. Feb 2010; (2) C. Kopp. The US Air Force Synthetic Fuels Program. Technical Report APA-TR-2008-0102. (2008)

Why do we scale-up?

ARGUMENT

capital cost ∝ area [L^2]
capacity ∝ volume [L^3]
capital cost / capacity ∝ [L^2]/[L^3]



pipe cross-section

FLAW

pipe thickness ignored
hoop stress (constant) ∝ t / r
capital cost ∝ $l \cdot r^2$
capital cost / capacity ∝ constant

Why is scale-up a problem?

#1 HUGE CAPITAL RISK

Shell Pearl GTL Facility, Qatar

MEGA-PROJECT ECONOMICS

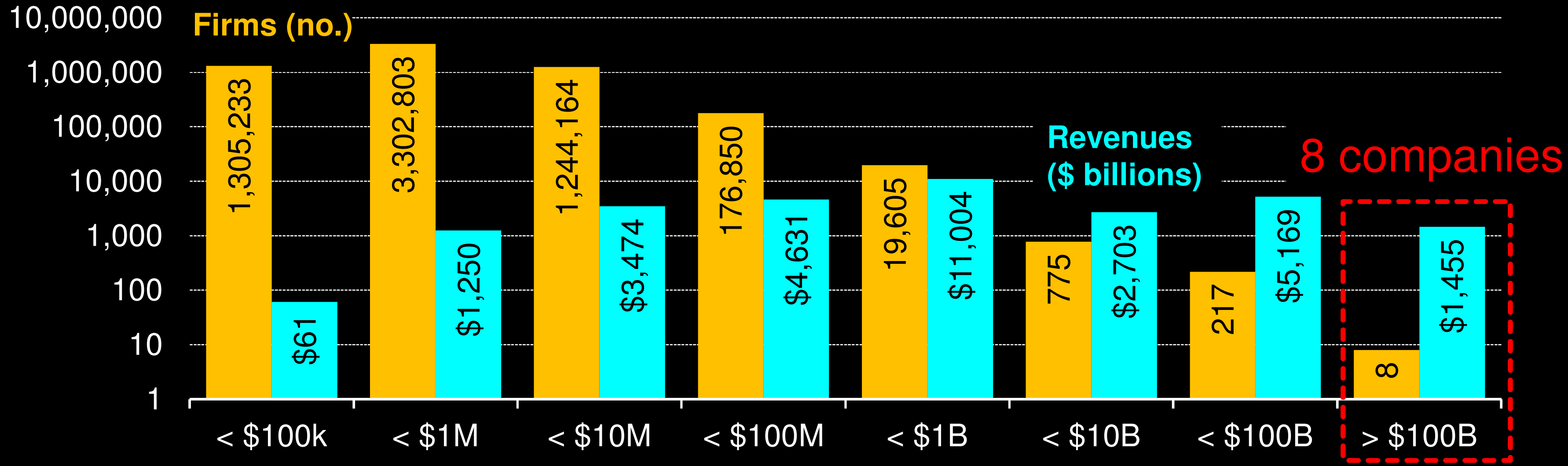
RAND Study:

- 52 mega-projects
- $0.5B and $10B (1984 dollars)
- average over budget = 90%

Source: E.W. Merrow. Understanding the outcomes of megaprojects: a quantitative analysis of very large civilian projects, The RAND Corporation, Santa Monica, CA, 1988.

Capital Resources

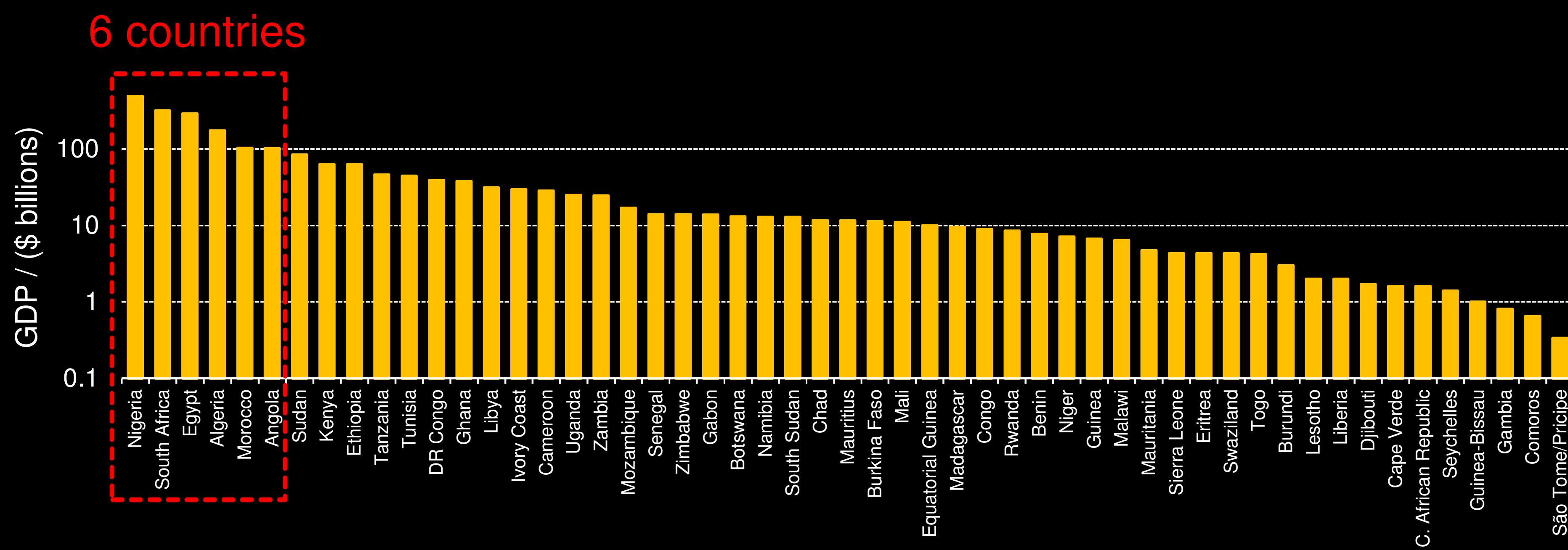
U.S. COMPANIES BY REVENUE, 2007



How many U.S. companies can finance a $1 billion plant?

Capital Resources

GDP OF AFRICAN COUNTRIES, 2015



How many African countries can finance a $1 billion plant?

Source: https://en.wikipedia.org/wiki/list_of_african_countries_by_gdp_(nominal)

Innovation Challenge

FINANCING ECONOMIES OF SCALE

GTL PLANT

(boe/d)	($/bpd)	plant cost
1	47,000k	$47M
10	10,000k	$100M
100	2,200k	$220M
1k	470k	$470M
10k	100k	$1,000M

POWER PLANT

(W_{th})	($/k$W_{th}$)	plant cost
100k	660,000	$65M
1M	140,000	$140M
10M	31,000	$300M
100M	6,600	$660M
1G	1,400	$1,400M

calculated from "2/3 scaling law"

Innovation Challenge

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POWER PLANT

(W_{th})	($/k$W_{th}$)	plant cost	
100k	660,000	$65M	R&D demo
1M	140,000	$140M	
10M	31,000	$300M	pilot demo
100M	6,600	$660M	
1G	1,400	$1,400M	commercial

calculated from “2/3 scaling law”

R&D Spending

OFFICE OF FOSSIL ENERGY

FY 2015	$561M
FY 2014	$570M
FY 2013*	$495M
FY 2012*	$337M
FY 2011	$434M
FY 2010	$660M
FY 2009	$876M
FY 2008	$465M

U.S. DEPARTMENT OF ENERGY

Pilot chemical or power plant requires **more than $200M.**

How can we continue to develop and deploy new technology with vastly inadequate and declining budgets?

*continuing resolution

#2 DISTRIBUTED CHALLENGES

Developing World

DISTRIBUTED MARKETS

AFRICA
17% WORLD POPULATION
1% WORLD FERTILIZER USE

In 1999, Uganda farmers bought urea for $600/ton, global market price was $100/ton, why?

- Market size (< 1% global market)
- Transport cost (>$50/ton, 30% total)
- Finance cost ($300k, 1 kton)

Source: World Bank, 2015

Rural Power

DISTRIBUTED MARKETS

ALASKA POWER EQUALIZATION PROGRAM, 2015

Program subsidizes energy costs between $0.15-$1.00/kWh

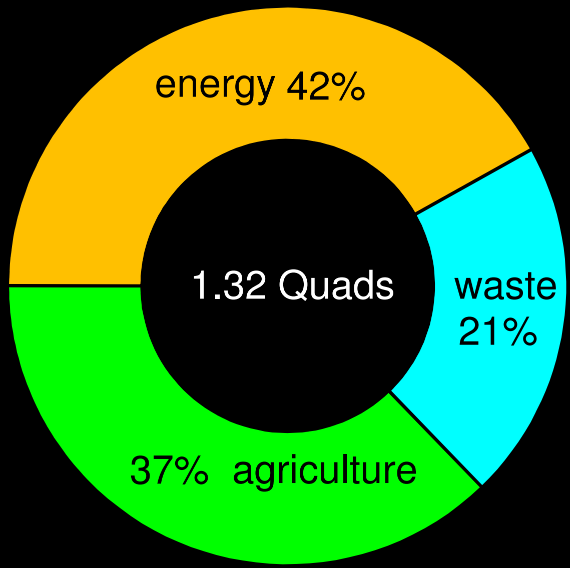
- Ave electricity price: $0.49/kWh
- Ave fuel oil price: $3.97/gal
- Subsidies paid: $37 million
- Fuel oil consumed: 27 million gal
- Ave resident energy: 5.500 MWh
- Population served: 81,969
- Communities served: 190

Source: http://www.akenergyauthority.org/Portals/0/Programs/PCE/Documents/FY15PCEStatisticalRprt.pdf?ver=2016-02-09-071157-843

Biogas

DISTRIBUTED RESOURCES

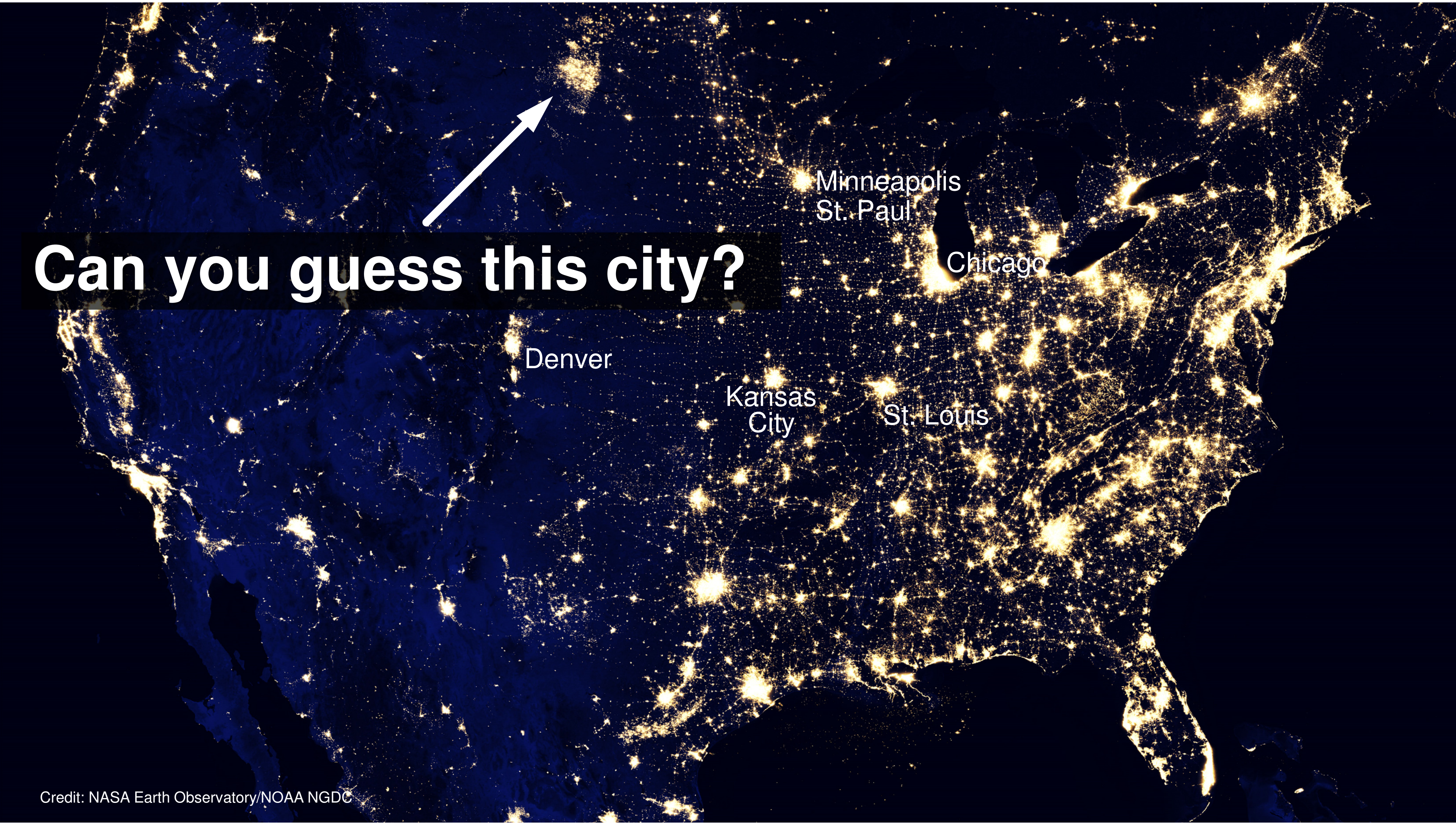
U.S. Methane Emissions in 2013



U.S. METHANE EMISSIONS

- 23-86x worse than CO_2
- 630 $Mt_{CO2,eq}$
- 10% GHG total
- 1.3 Quads

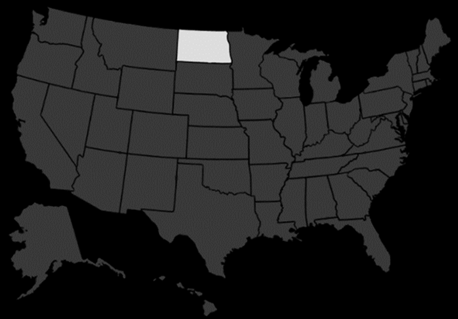
Source: http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html#fullreport

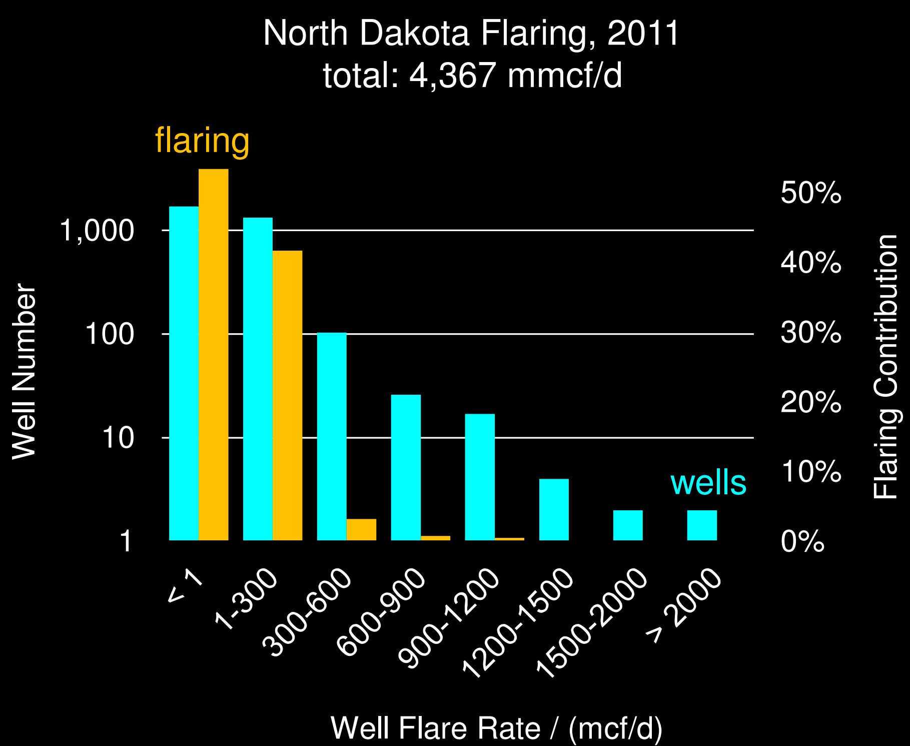


Can you guess this city?
Minneapolis
St. Paul
Chicago
Denver
Kansas
City
St. Louis
Credit: NASA Earth Observatory/NOAA NGDC

Natural Gas Flaring

DISTRIBUTED RESOURCES





NORTH DAKOTA FLARING

- North Dakota flares roughly 20% of produced natural gas
- Most flaring is under 300 mcf/d, but highly time dependent
- Small wells are uneconomical to bring to market

PROBLEM #1

BARRIER TO INNOVATION

Today's approach for deploying energy technology is to scale-up to huge size to achieve economies of scale, but this requires taking huge capital risk and consequently low technology risk—stifling the deployment of technological innovation

PROBLEM #2

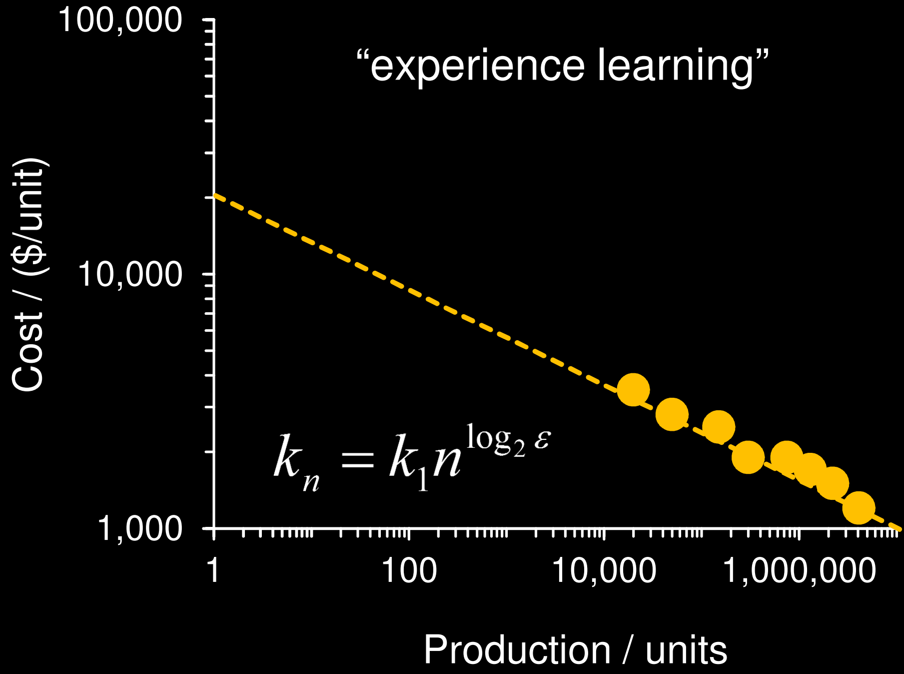
DISTRIBUTED CHALLENGES

The energy landscape has dramatically changed over the last decade—presenting new challenges that are fundamentally distributed in nature and for which today's solutions are inadequate

How do we break the hegemony of scale-up?

Economies of Unit Number

FORD MODEL T, 1909-1916



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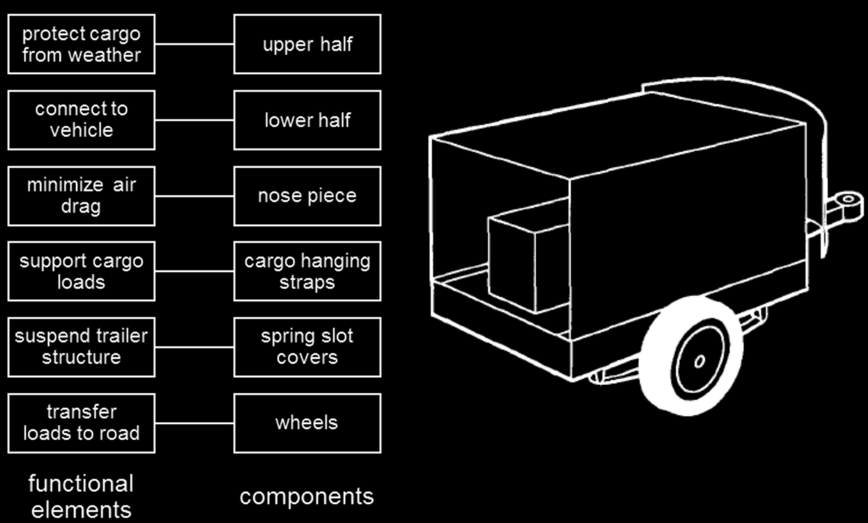
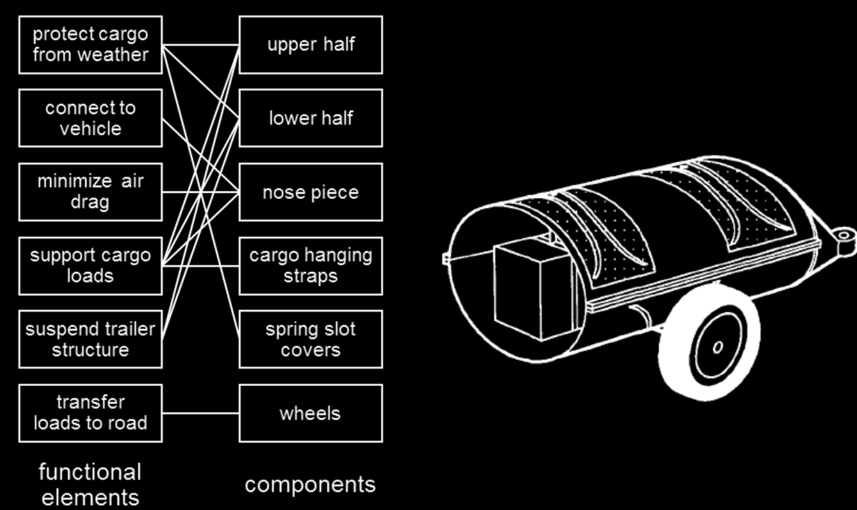
Modular Design

MODULAR VS INTEGRAL

MODULAR



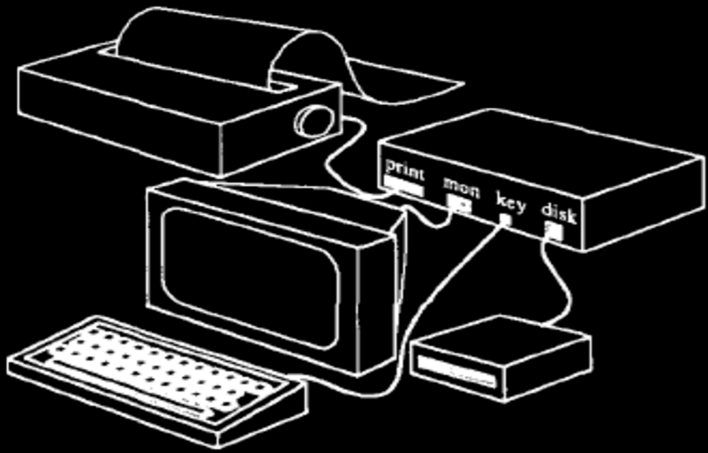
INTEGRAL



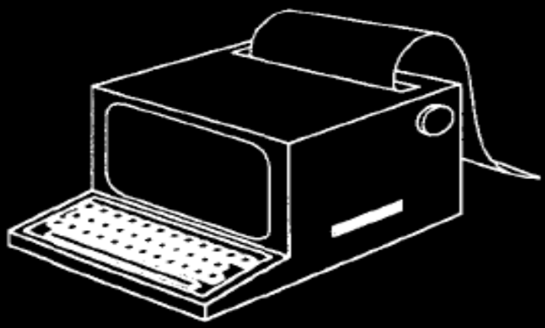
Modular Design

MODULAR VS INTEGRAL

MODULAR



INTEGRAL



Small Modular

OIL REFINERY (WORLD)

- 7 TW petroleum refining
- 700 plants
- $500/kW capex

AUTO ENGINES (U.S.)

- 1.3 TW motive power
- 250 million engines
- $50/kW capex

Small Modular

GAS TURBINES (U.S.)

- 0.2 TW electricity
- 5000 gas turbine generators
- $1000/kW capex

AUTO ENGINES (U.S.)

- 1.3 TW motive power
- 250 million engines
- $50/kW capex

Small Modular

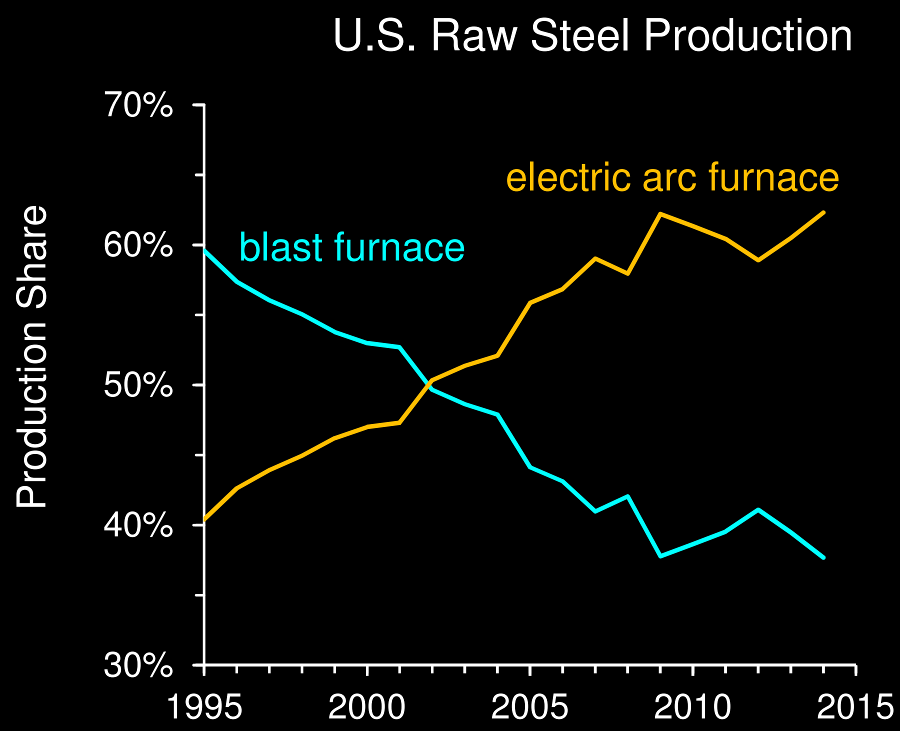
STEEL PRODUCTION

Integrated Mills

- blast furnace
- capacity > 2.0 million ton/y

Mini-Mills

- electric arc furnace
- capacity < 0.5 million ton/y



Source: AISI, 2014

Why now?

Why now?

ENABLING TECHNOLOGIES

- Additive Manufacturing – process intensification
- Machine Learning – automation
- Global Communications – remote control

Example

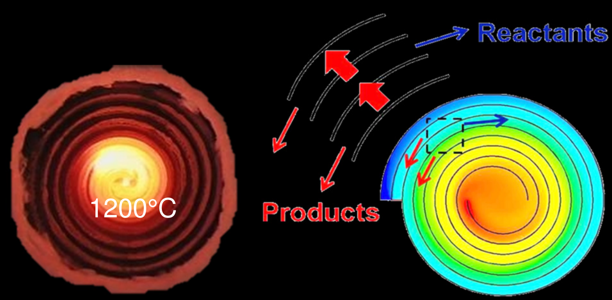
OVERCOMING SCALE-UP

1. Residence Time

   fundamental limit = gravity
   e.g. solution = centrifugal force

2. Adiabatic Operation

   fundamental limit = surface/volume
   e.g. solution = thermal integration



additive manufacturing enables novel reactors designs previously thought impossible/impractical

What will be the impact?

Democratization through Innovation

1450	1908	1950	1973	????
Gütenburg Press	Ford Model T	ISO Shipping Container	Motorola DynaTAC 8000X	Modular Energy System
INFORM	TRANSPORT	SHIP	COMMUNICATE	ENERGY

Isaac Mkalia, 20, checks his mobile phone in Kojiado district, near the Tanzanian border (Photograph: Sven Torfinn/Oxfam)

Thank You

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