Welcome to Snowmass Day 2

Session 4: Infrastructure and Technology Deployment in Transformation Pathways

- What are indicators of infrastructure and technology transformation?
- What barriers could be encountered, and what does this imply for the pace of transformation?

Session 5: Institutions in Transformation Pathways

- How will existing institutions and institutional change shape pathways?
- What barriers could be encountered, and what does this imply for the pace of transformation?

ExxonMobil

July 21, 2016

Perspectives on the Transformation of Infrastructure and Technology

Haroon Kheshgi

Energy lives here™

Outline

- Perspectives
- Transformation
- Infrastructure
- Technology

Perspectives

Emerging Energy Technology

Investing to meet growing energy demand and manage climate change risks

Increase Supply

- Advanced biofuels and algae
- Natural gas to products

Expand Energy Access

- Hydrocarbon and renewable energy systems
- Power generation technologies

Improve Efficiency

- Internal combustion engine efficiency
- Light-weighting and packaging reduction

Mitigate Emissions

- Carbon capture and sequestration
- Methane emissions reduction

Good Science for Sound Policy

- Climate science, economics, and policy
- Resilience and preparedness

Source: Exxon Mobil Annual Shareholders Meeting, May 2016

let's talk about climate change

Much has been said recently about ExxonMobil and our views on climate change. So we'd like to take this opportunity to set out, clearly and concisely, our position on this important issue.

- The earth's climate has warmed about 0.7°C in the last century
- Many global ecosystems are showing signs of warming
- CO_2 emissions have increased

Climate science remains extraordinarily complex. So for over 15 years, our scientists have been participating directly in the preparation of the Intergovernmental Panel on Climate Change (IPCC) reports, which are an important contribution to climate science. In addition, we're already taking steps to address the challenge of reducing greenhouse gas emissions in effective and meaningful ways. A few examples:

- We are working with governments and leading universities on technology breakthroughs to produce energy with reduced emissions
- We are working with auto and engine makers on programs that could improve fuel economy by as much as 30 percent
- We are working with academics, NGOs and governments to de ne meaningful policy approaches

Businesses, governments and NGOs are faced with a daunting task: selecting policies that balance economic growth and human development with the risks of climate change. The challenge is enormous, and we continue to work positively and constructively on meaningful approaches. TO LEARN MORE, GO TO **exxonmobil.com/climate**.

ExxonMobil

Taking on the world's toughest energy challenges.™

Climate science remains extraordinarily complex.

So for over 15 years, our scientists have been participating directly in the preparation of IPCC reports, which are an important contribution to climate science.

Source: Washington Post Ad, February 2007

30+ Years of Participation…

IPCC 2007

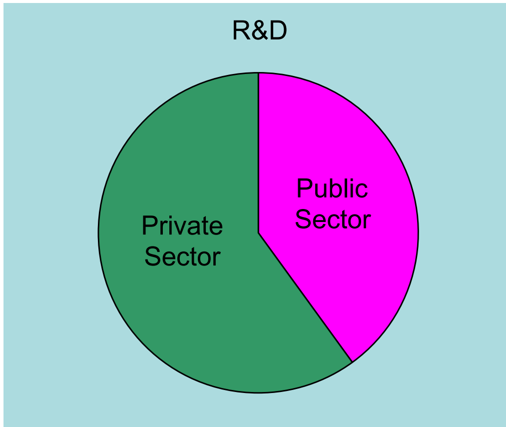
Source: IISD 2007

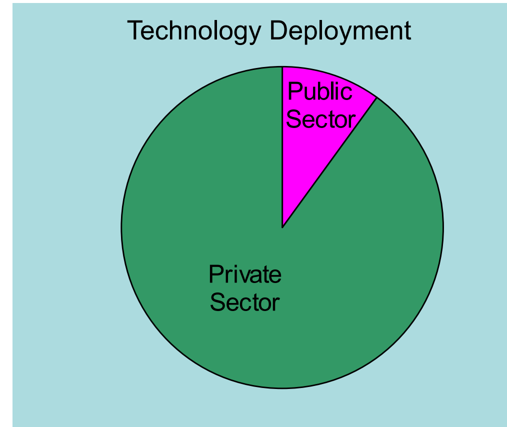
30+ Years of Participation…

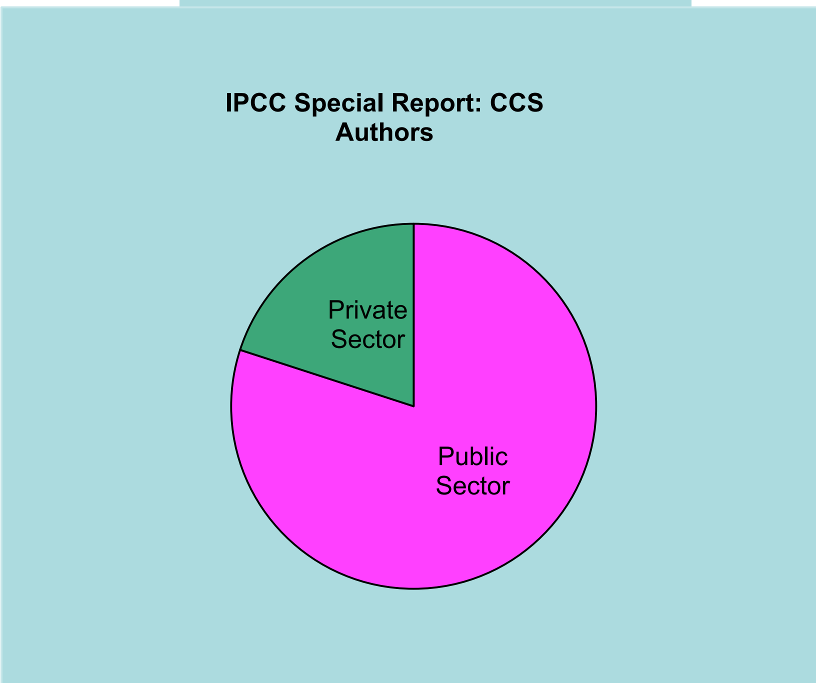
1991

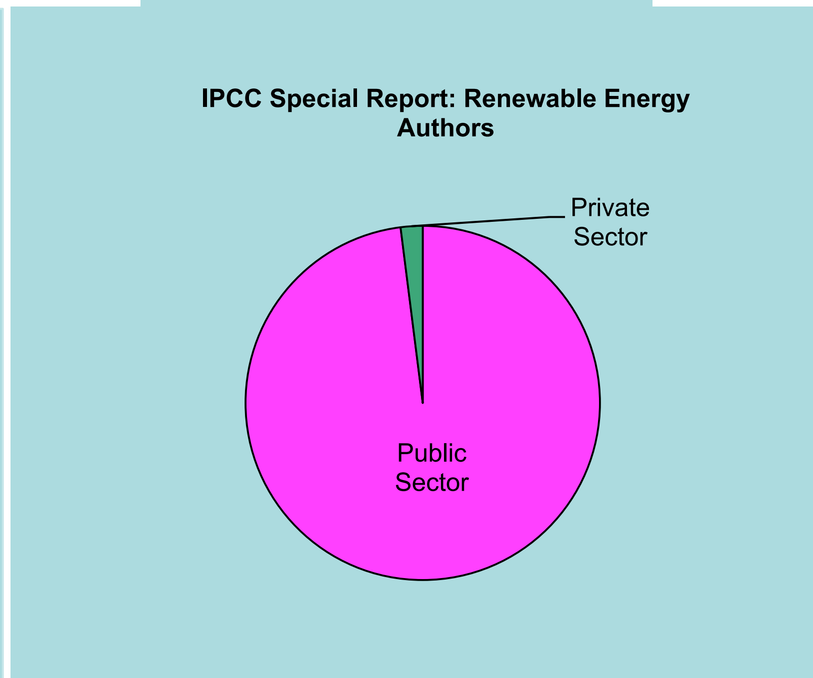
Engagement of Business Expertise and Perspective in the Preparation of IPCC Reports?

IPIECA





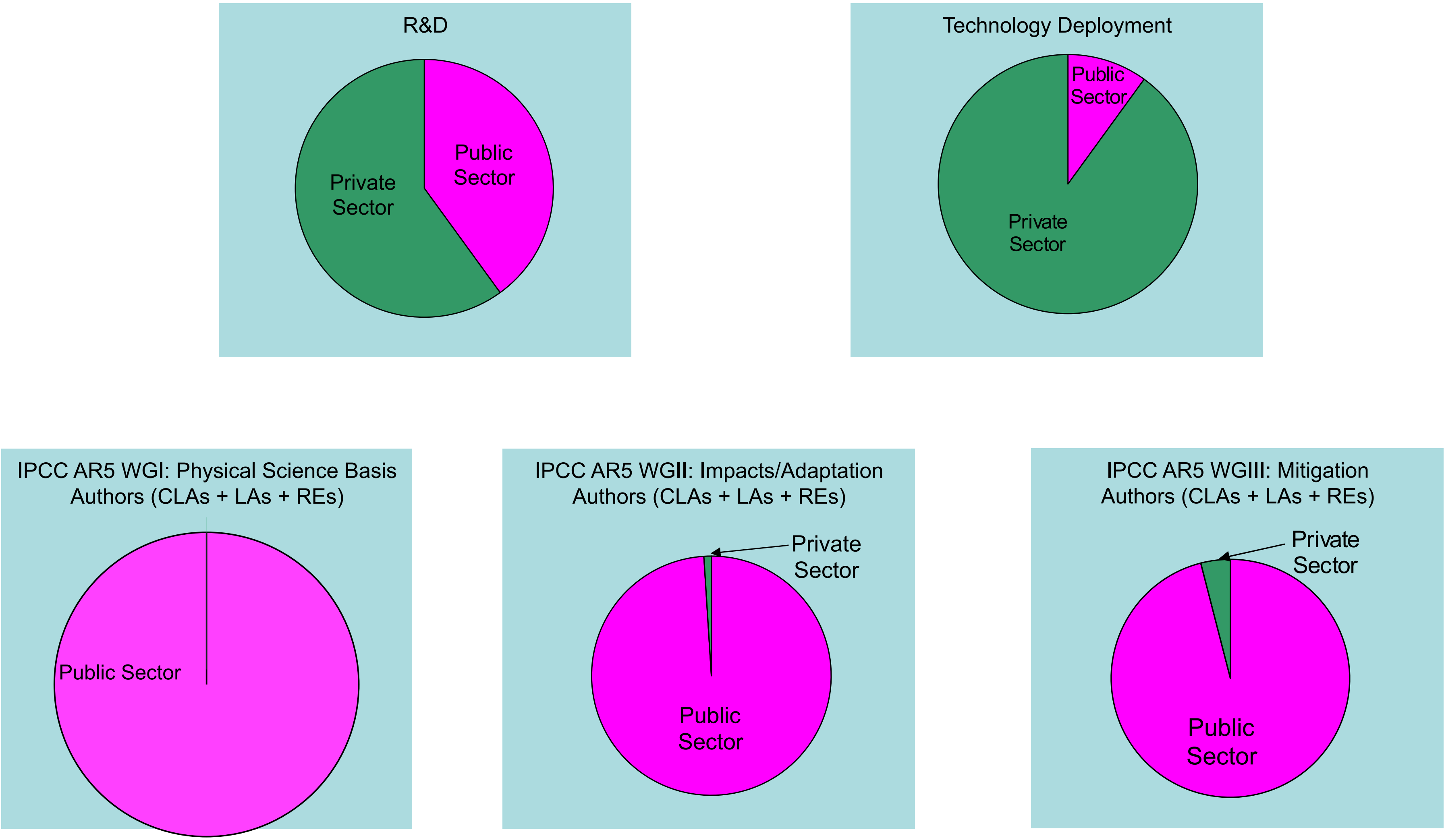




R&D spending for OECD (R&D statistics)

Source: Kheshgi, 2010 IPCC Expert Review Meeting on the SRREM, and 2014 IPIECA workshop on the AR5

Engagement of Business Expertise and Perspective in the Preparation of IPCC Reports?

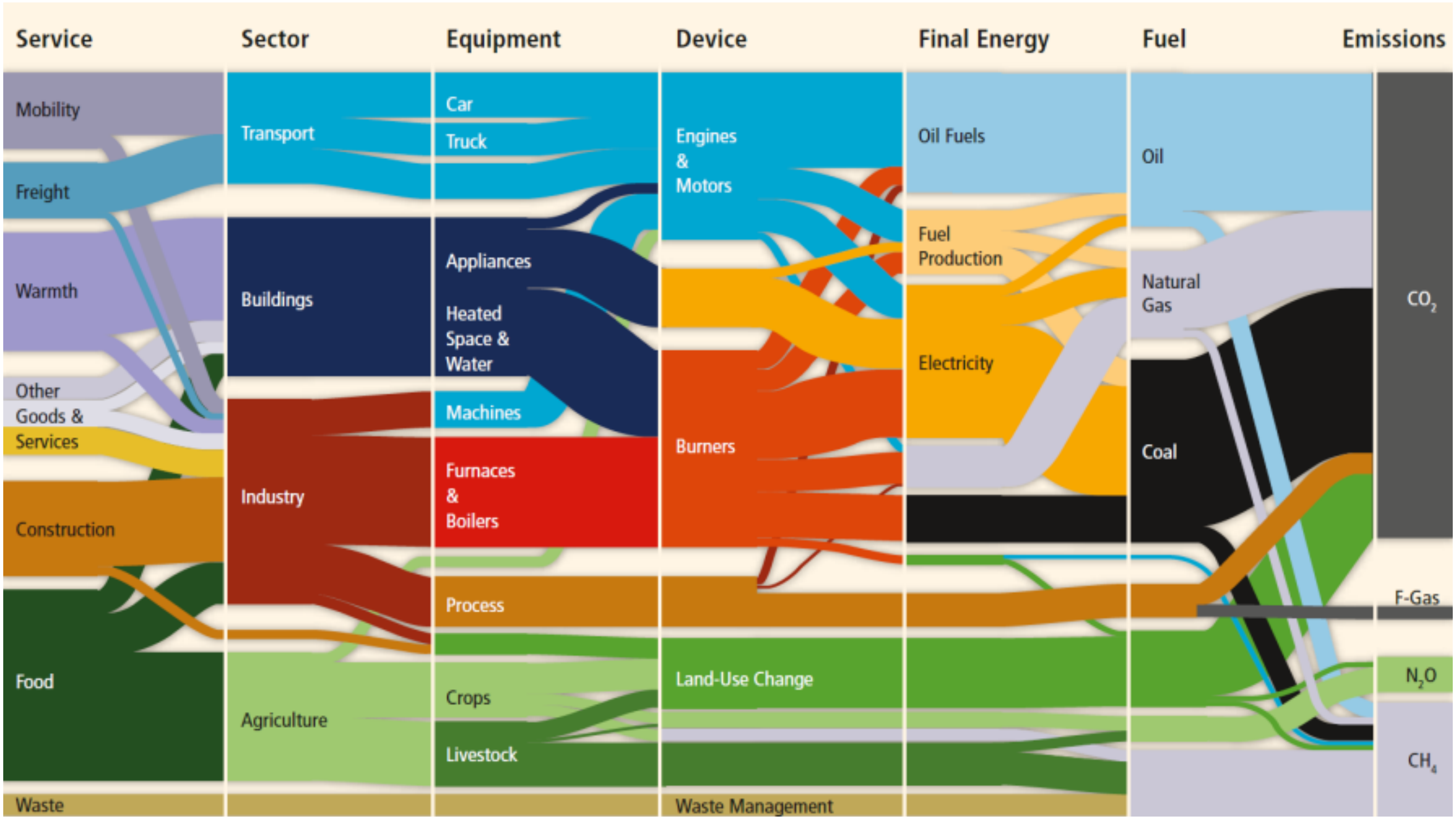


Source: Kheshgi, 2012 IPCC Expert Review Meeting on the AR5, and 2014 IPIECA workshop on the AR5

R&D spending for OECD (R&D statistics)

Transformation

Long-Term Stabilization Requires Transformation



Source: IPCC AR5 WG3, Ch 10 (2014)

Long-Term Stabilization Requires Transformation

Efficiency / Reduce Demand → **Decarbonize Global Economy** → **Negative GHG Emissions**

	Energy Intensity in 2050 (MJ per $ GDP)	Carbon per unit of Energy in 2050 (kg C per GJ)	Negative GHG Emissions (Year)	Mean °C Rise in 2100
Current	*12*	*18*	*-*	*0.8*
RCP 8.5	**9**	**18**	**-**	**4.3**
RCP 4.5	**7**	**14**	**-**	**2.4**
RCP 2.6	**5**	**5**	**2070**	**1.6**

Sources: van Vuuren *et al.*, Climatic Change (2011); IPCC AR5 (2013)

Pace of Investment Inadequate

Reducing GHGs 50% below 2005 by 2050 requires all steps below:

Investment	Required Annual Additions 2005 – 2050	Annual Additions Since 2005
Nuclear plants, 1,000 MW	30	< 1
Coal and gas plants with CCS, 500 MW	55	< 1
Wind turbines, 4 MW	15,600	8,100
Solar PV, m^2 panels	325 million	370 million

Required Annual Additions 2015 – 2050
~40
~70
~18,000
~315 million

Source: IEA Energy Technology Perspectives 2010: Scenarios and Strategies to 2050

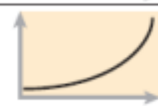
CCS: Recommendations Advanced Initiated by Gleneagles G8 (2005)

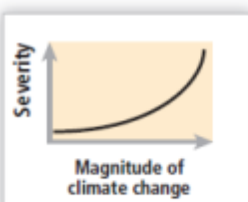
- Demonstrating CO_2 capture and storage
- Taking concerted international action
- Bridging the financial gap for demonstration
- Creating value for CO_2 for commercialisation of CCS
- Establishing legal and regulatory frameworks
- Communicating with the public
- Infrastructure
- Retrofit with CCS capture

Source: IEA/CSLF Report to the Muskoka 2010 G8 Summit

Climate Impacts in the Context of Other Drivers

Table 10-10 | Summary of findings.

Sector	Climate change drivers	Sensitivity to climate change	Sign	Other drivers	Relative impact of climate change to other drivers
Winter tourism	• Temperature • Snow		Negative	• Population • Lifestyle • Income • Aging	Much less
Summer tourism	• Temperature • Rainfall • Cloudiness		Negative for suppliers in low altitudes and latitudes Positive for suppliers in high altitudes and latitudes Neutral for tourists	• Population • Income • Lifestyle • Aging	Much less
Cooling demand	• Temperature • Humidity • Hot spells		Positive for suppliers Negative for consumers	• Population • Income • Energy prices • Technology change	Less
Heating demand	• Temperature • Humidity • Cold spells		Negative for suppliers Positive for consumers	• Population • Income • Energy prices • Technology change	Less
Health services	• Temperature • Precipitation		Positive for suppliers Negative for consumers	• Aging • Income • Diet/lifestyle	Less
Water infrastructure and services	• Temperature • Precipitation • Storm Intensity • Seasonal Variability		Negative for water users Positive for suppliers Spatially heterogeneous	• Population • Income • Urbanization • Regulation	Less in developing countries Equal in developed countries
Transportation	• Temperature • Precipitation • Storm intensity • Seasonal variability • Freeze/thaw cycles		Negative for all users Positive for transport construction industry	• Population • Income • Urbanization • Regulation • Mode shifting • Consumer and commuter behavior	Much less in developing countries Less in developed countries
Insurance	• Temperature • Precipitation • Storm intensity • Seasonal variability • Freeze/thaw cycles		Negative for consumers Neutral for suppliers	• Population • Income • Regulation • Product innovation	Less or equal in developing countries Equal or more in developed countries



Source: AR5 WG2 Ch10, Arent et al. 2014

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Infrastructure

Observations

- Engineers and engineering societies offer unique and significant expertise and experience in addressing knowledge gaps and implementation barriers
  - Bring relevant engineering disciplines to bear in the development and evaluation of energy technology systems.
  - Improve Communication: both within their memberships, and externally with public interest organizations, governmental agencies, educational institutions, business, and the general public; engineering societies also have international reach

Source: Kheshgi 2010, NAE Engineering Convocation

Funded by the United Engineering Foundation

Gaps & Barriers Workshop October 21/22, 2009

Workshop Participants

Organizing Task Team

Arnold Feldman, Dale Keairns, Haroon Kheshgi (chair), Veronika Rabl, Darlene Schuster, Richard Wright

Summary Posted on the Workshop Website:
http://fscarbonmgmt.org

Source: Kheshgi 2010, NAE Engineering Convocation

Funded by the United Engineering Foundation

Observations

- Achieving proposed goals would entail extraordinary changes in:
  - development and implementation of technology
  - streamlining of regulations to allow these changes, and
  - policies that would drive these changes worldwide

Source: Kheshgi 2010, NAE Engineering Convocation

Funded by the United Engineering Foundation

Observations

- Addressing the gaps and barriers requires solutions spanning technology, regulation, and policy
- Public and decision makers' expectations of the pace and scale of technology change are much higher than can realistically be achieved given the current state of technology, regulation and policy

Source: Kheshgi 2010, NAE Engineering Convocation

Observations

- Energy and material resource availability is critical to most potential mitigation options
- Availability of human resources is important to achieving the goals.

Source: Kheshgi 2010, NAE Engineering Convocation

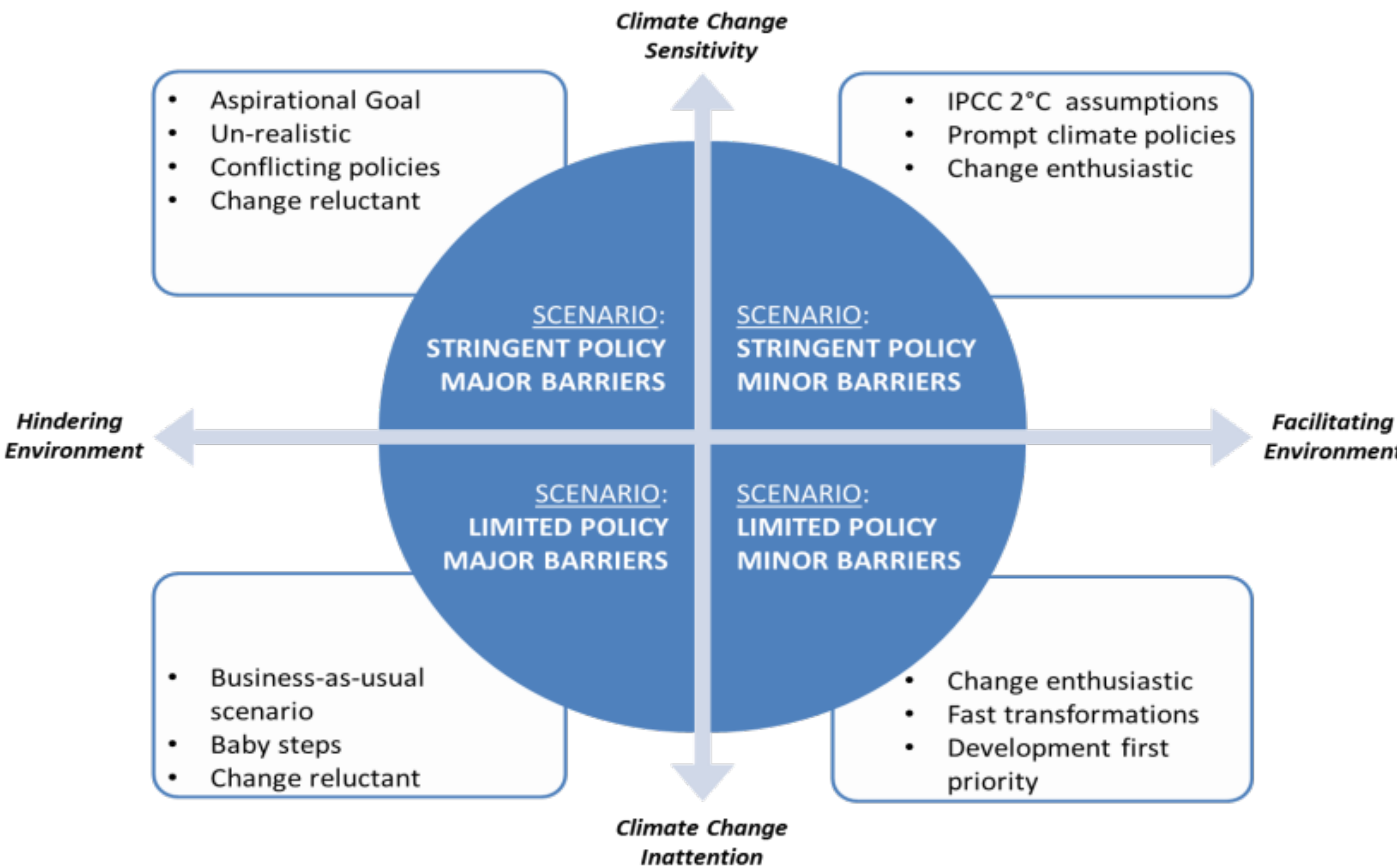
Barriers to GHG Reduction Options: Industry

Table 10.6 | Barriers (–) and opportunities (+) for GHG emission reduction options in industry. References and discussion appear in respective sub-sections of 10.9.

	Energy efficiency for reducing energy requirements	Emissions efficiency, fuel switching and CCS	Material efficiency	Product demand reduction	Non-CO_2 GHGs
Technological Aspects: Technology	+ many options available – technical risk + cogeneration mature in heavy industry – non-transparent and technically demanding interconnection procedures for cogeneration	+ fuels and technologies readily available – retrofit challenges + large potential scope for CCS in cement production, iron and steel, and petrochemicals – limited CCS technology development, demonstration and maturity for industry applications	+ options available	– slower technology turnover can slow technology improvement and operational emission reduction	+/– approaches and technologies available for some sources – lack of lower cost technology for PFC emission reduction in existing aluminium production plants
Technological Aspects: Physical	+ less energy and fuel use, lower cooling needs, smaller size – concentrating suitable heat loads for cogeneration – retrofit constraints on cogeneration	– lack of sufficient feedstock to meet demand – CCS retrofit constraints – lack of CO_2 pipeline infrastructure – limited scope and lifetime for industrial CO_2 utilization	+ reduction in raw and waste materials – transport infrastructure and industry proximity for material/waste reuse	+ reduction in raw materials and disposed products	– lack of control of HFC leakage in refrigeration systems
Institutional and Legal	– impact of non-energy policies + energy efficiency policies (10.11) – market barriers – regulatory, tax/tariff and permitting of cogeneration +/– grid access for cogeneration		– fragmented and weak institutions	– regulatory and legal instruments generally do not take account of externalities	– lack of certification of refrigeration systems – regulatory barriers to HFC alternatives in aerosols
Cultural	– lack of trained personnel +/– attention to energy efficiency – lack of acceptance of unconventional manufacturing processes – cogeneration outside core business – lack of consumer and policymaker knowledge of cogeneration	– social acceptance of CCS	+/– public participation – human capacity for management decisions	+/– user preferences drive demand	– lack of information/education about solvent replacements – lack of awareness of alternative refrigerants
Financial	– access to capital and short investment payback requirements – high overhead costs for small or less energy intensive industries +/– factoring in efficiency into investment decisions (e.g., energy management) + cogeneration economic in many cases +/– market value of grid power for cogeneration – high capital cost for cogeneration	– lack of sufficient financial incentive for widespread CCS deployment – liability risk for CCS – high CCS capital cost and long project development times	– upfront cost and potentially longer payback period + reduced production costs	– businesses, governments, and labour favour increased production	– recycled HFCs not cost competitive with new HFCs – cost of HFC incineration

Source: AR5 WG3 Ch10, Fischedick et al. 2014

Transformation is Subject to Practical Barriers



Source: Muratori et al. 2016

Technology

REVIEW: ENGINEERING

Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet

Martin I. Hoffert,[1*] Ken Caldeira,[3] Gregory Benford,[4] David R. Criswell,[5] Christopher Green,[6] Howard Herzog,[7] Atul K. Jain,[8] Haroon S. Kheshgi,[9] Klaus S. Lackner,[10] John S. Lewis,[12] H. Douglas Lightfoot,[13] Wallace Manheimer,[14] John C. Mankins,[15] Michael E. Mauel,[11] L. John Perkins,[3] Michael E. Schlesinger,[8] Tyler Volk,[2] Tom M. L. Wigley[16]

What are the technological options to produce ~10-30 TW emission free energy … by 2050?

A variety of technology families considered:

- **Renewables**
- **Fission and Fusion**
- **Sequester carbon from fossil-fuels**
- **Efficiency**
- **Geoengineering**

All of these approaches currently have severe deficiencies that limit their ability to stabilize global climate

Science 298, pp. 981-987, 1 Nov 2002

R&D in Long Term Carbon Management

- Goal: to create economically justified options for future technologies that make a difference to global energy mix

- Tax payer funded R&D should seek to identify fundamental barriers to acceptable technology and find solutions that improve
  - Performance
  - Cost
  - Safety
  - Environmental acceptability

- Taxpayer funded R&D should not waste resources optimizing (let alone subsidizing) currently uneconomic technology

- Private sector should bear the risk and capture reward of developing commercial technology that competes in the market

Source: Flannery and Kheshgi (2004) IPCC Expert Meeting on Industrial Technology Development, Transfer and Diffusion

Private Sector Role

- Profitable multi-national companies with strategic emphasis on R&D play an essential role in development and global deployment of advanced technologies

- Commercial opportunity typically derives from advanced technology and effective management systems (proprietary positions and know how)--especially with advanced technology

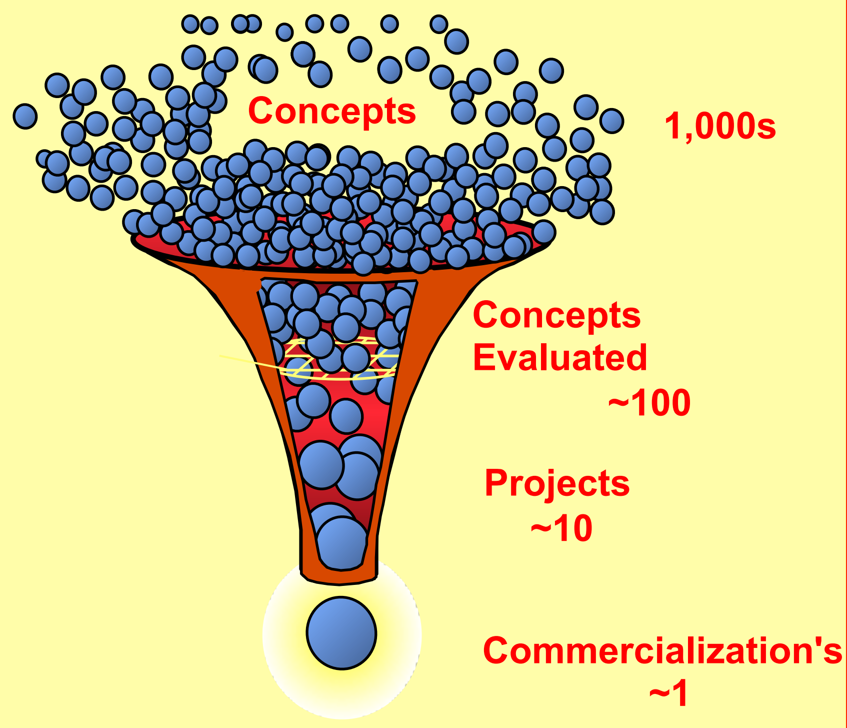
  Financial controls   Operations integrity
  Energy management   Maintenance
  ...

- Enabling frameworks/capacity are essential to deliver benefits
  - Rule of law
  - Safe, stable environment for workers and communities
  - Open markets
  - Realization of mutual benefits
  - Protection of intellectual property
  - Movement of goods, capital and people
  - Respect for the needs of host governments and communities
  - ...

Source: Flannery and Kheshgi (2004) IPCC Expert Meeting on Industrial Technology Development, Transfer and Diffusion

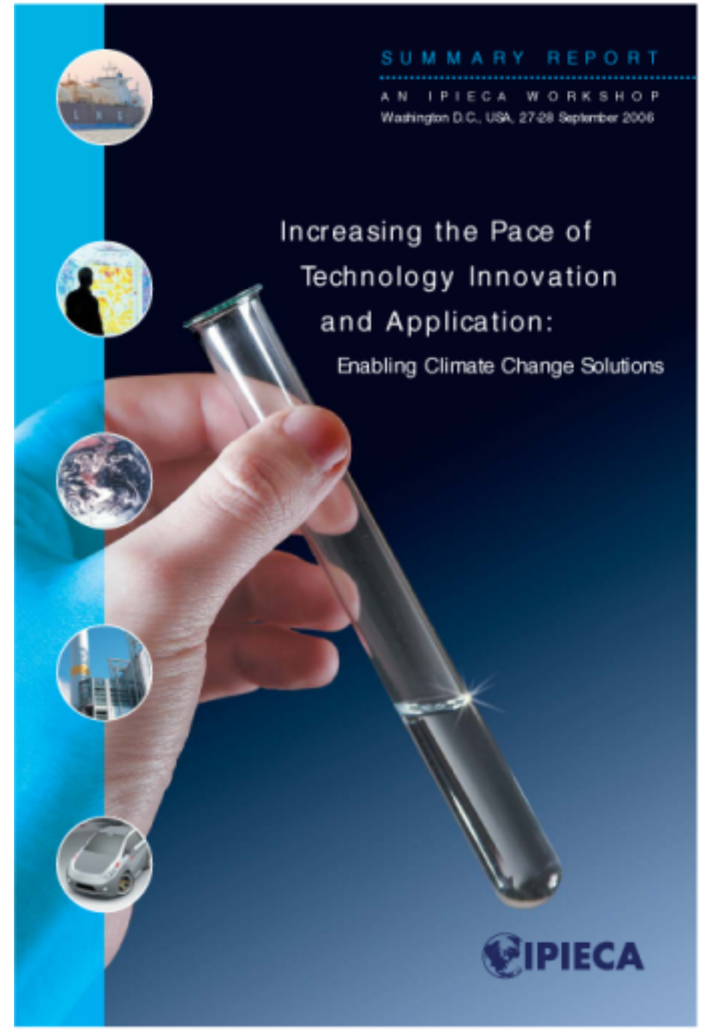
Technology: Observations and Conclusions

- *Significant technology advances are critical to provide options for deep reductions in GHG emissions while providing affordable energy services*
- *Technology R&D/innovation are actively managed in the private sector*
    - *Concept/idea generation*
    - *R&D/innovation of concepts*
    - *Commercialization once all appropriate considerations are addressed*
- *How to accelerate the pace of energy technology innovation and application should be one focus of policy development*



Process Industry Experience on Breakthrough Research

Thank You!



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