Global Climate Stabilization Studies

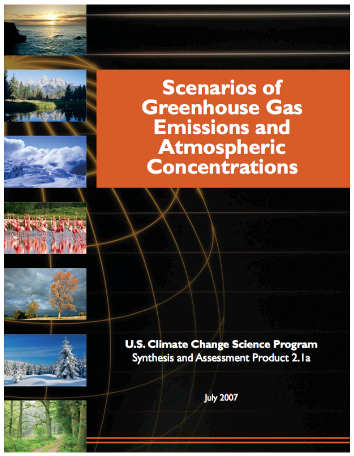
A Literature Review

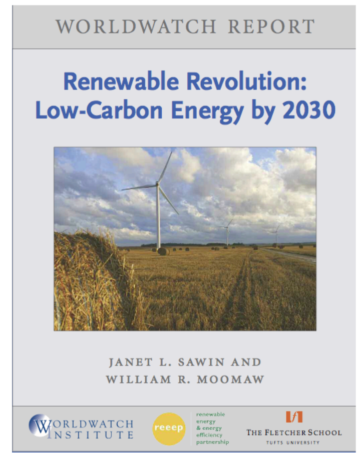
DRAFT

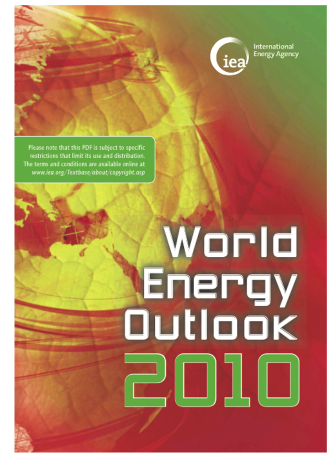
March 24, 2011

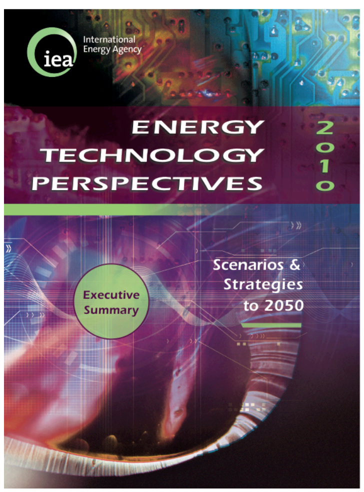
Purpose of study

To provide an “apples-to-apples” comparison of a set of global climate stabilization studies, evaluating and reviewing the various targets and scenarios on a consistent basis.



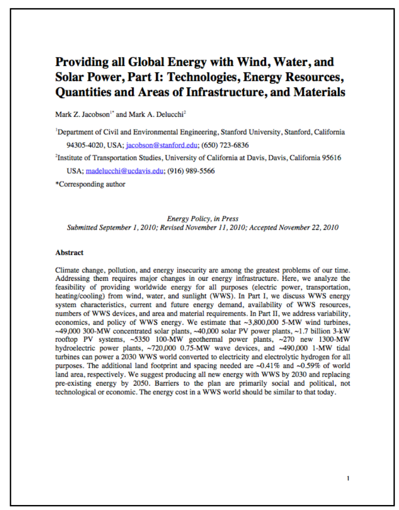






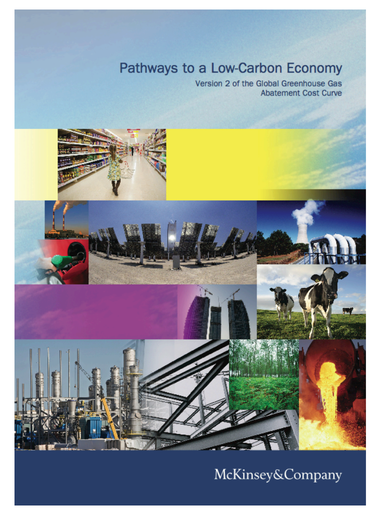

Energy Economics

International climate policy architectures: Overview of the EMF 22 International Scenarios


Providing all Global Energy with Wind, Water, and Solar Power, Part I: Technologies, Energy Resources, Quantities and Areas of Infrastructure, and Materials

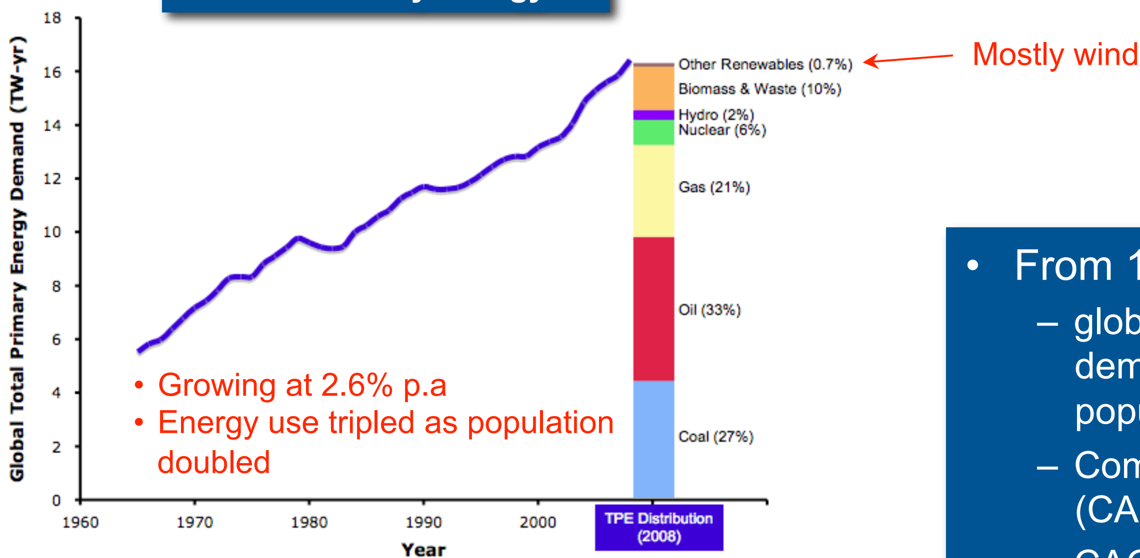
Mark Z. Jacobson and Mark A. Delucchi

Abstract

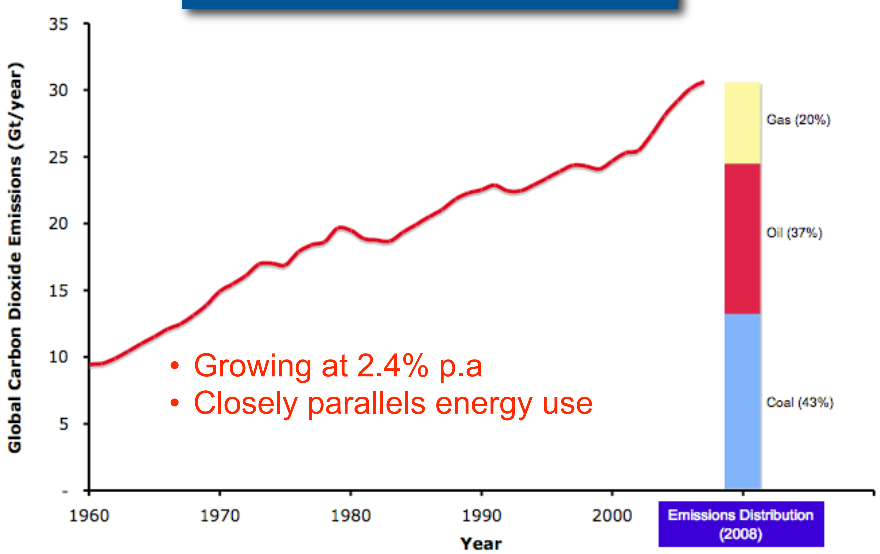


Background Global TPE & Carbon Emissions Trends

Total Primary Energy



Carbon Dioxide Emissions



- From 1965 - 2008:
  - global total primary energy (TPE) demand roughly tripled as global population roughly doubled.
  - Compound annual growth rate (CAGR) of TPE was 2.6%.
  - CAGR of carbon emissions was 2.4%.
- In 2008, TPE was more than 80% fossil with “new” renewables (mainly wind) ~ 0.7%.

Background Kaya Identity Trends and Historical Deployment Rates

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Kaya Identity Trends

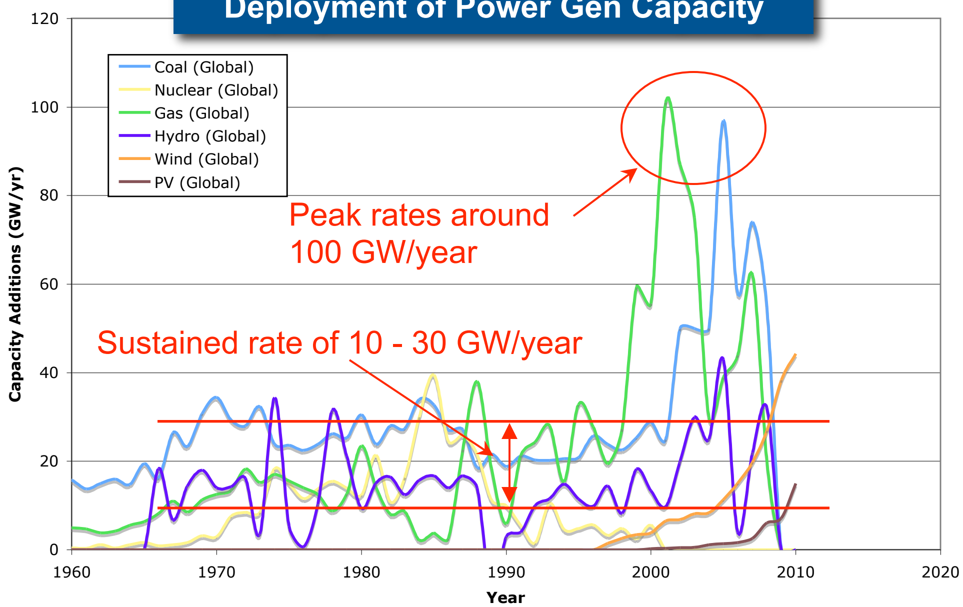
Carbon Intensity	Average Annual Percent Change		
	1990 – 2005	2005 – 2020	2020 – 2035
Total World	-0.1	-0.3	0.0
OECD	-0.2	-0.5	-0.1
Non-OECD	0.0	-0.3	0.0
Energy Intensity			
Total World	-1.5	-2.0	-1.6
OECD	-1.2	-1.7	-1.5
Non-OECD	-1.5	-2.8	-1.7

- Essentially no improvement, past or predicted.
- Post 2001, Chinese CI has INCREASED at 1.3%

- Not much change from historical 1.5% improvement

Carbon intensity = Carbon emitted per Joule consumed.
Energy intensity = Joules consumed per dollar of GDP produced.

Deployment of Power Gen Capacity



- Since 1990, energy intensity has declined at 1.5% p.a. while carbon intensity has barely improved at all.
- BAU projections to 2035 show no change from this pattern.
- Largest decline in carbon intensity since 1990 was during re-building of old Soviet infrastructure (-0.7% p.a.).
- Since 2001, carbon intensity in China has increased at +1.3% p.a.
- Capacity has been added at sustained rates of 10 - 30 GW/yr for a variety of technologies.
- Peak additions of note:
  - 90 GW coal in China in 2006
  - 60 GW GTCC in US in 2002
- Global capacity in 2008 was ~4200 GW. Approximately 2100 GW of this total has been built in the last 20 years.

Background Business-as-Usual Projections of TPE

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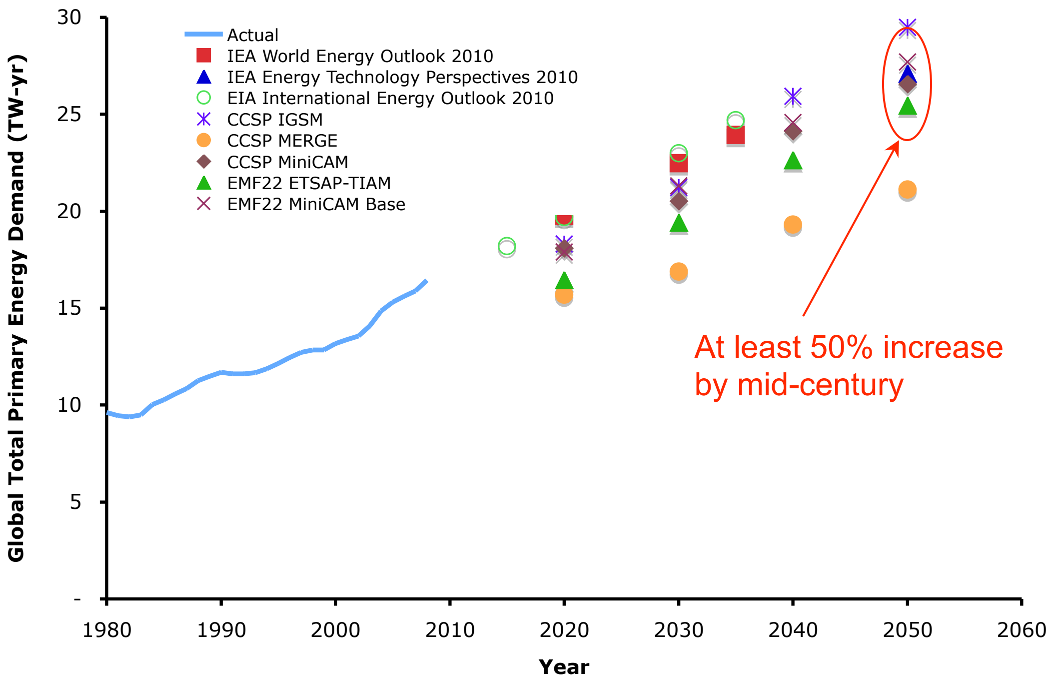
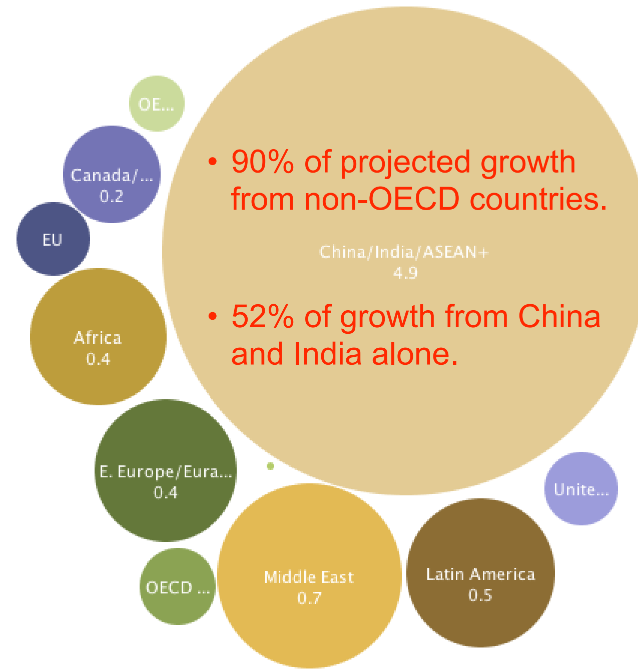
Various Projections of TPE



Change in TPE 2008 - 2035 by Region

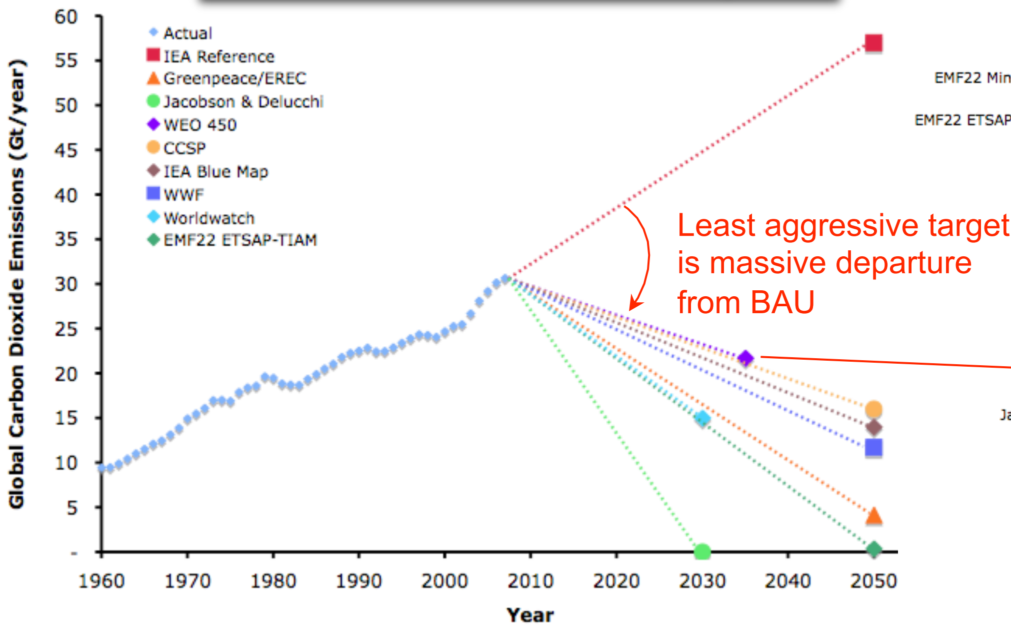


IEA WEO 2010

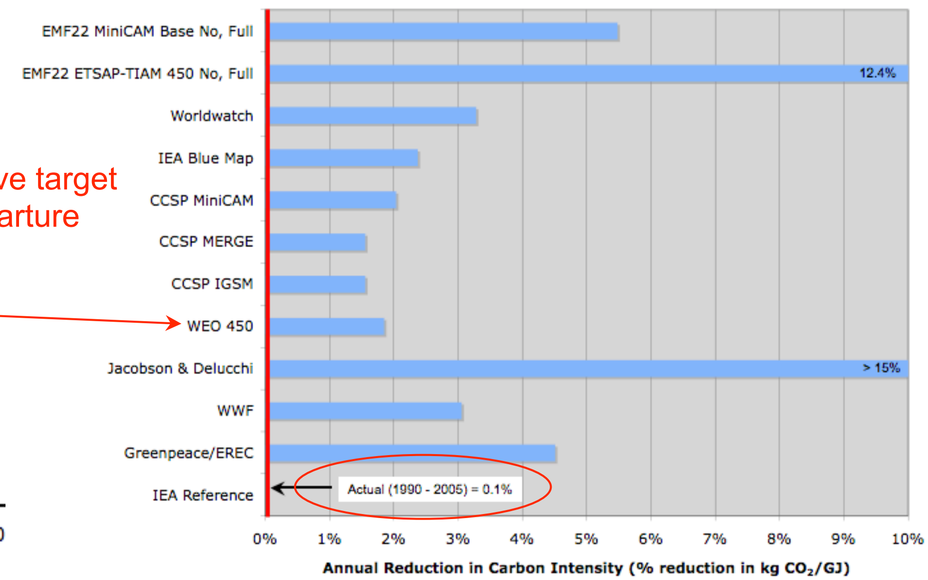
- Most BAU scenarios call for at least a 50% increase in TPE by mid-century.
- Non-OECD countries account for 90% of the projected growth from 2008 to 2035, with China and India alone accounting for 52% of the growth.

Carbon Emissions Targets

Carbon Dioxide Emissions Targets



Implied Carbon Intensity Reductions



- Some reports presented several targets: most aggressive target was selected.
- Even the mildest targets in the set (e.g., WEO 450 or CCSP) would require a radical change of direction in carbon emissions trends.
- Implied reductions in carbon intensity range from 1.5% to more than 10% p.a., compared to the historical 0.1%.

Total Primary Energy Demand Projections

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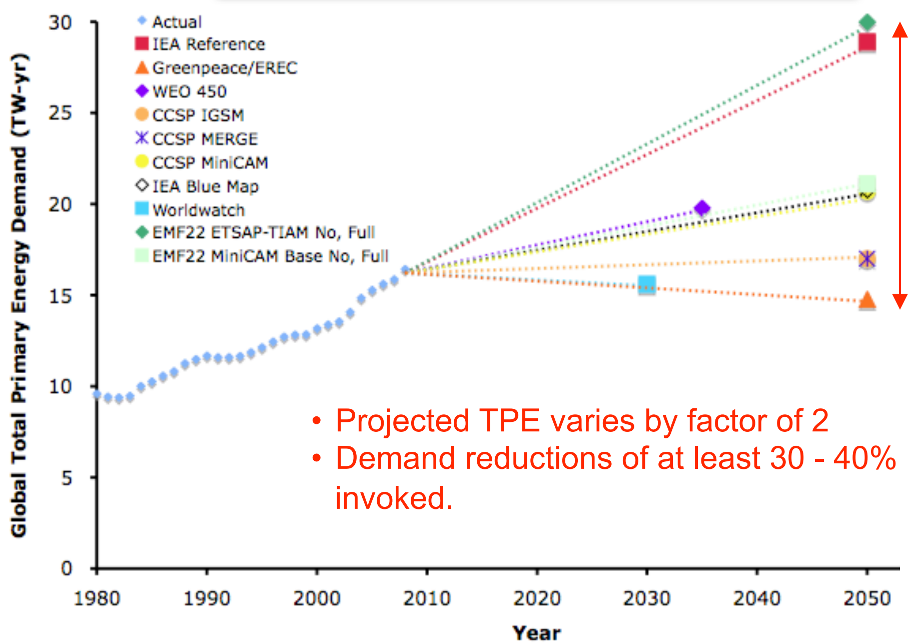
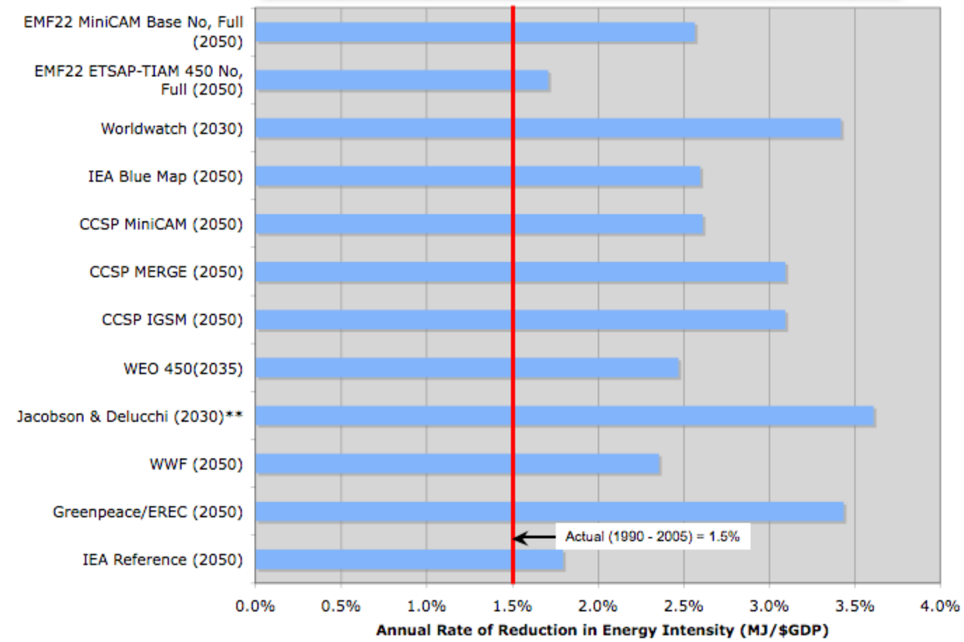
Projected Total Primary Energy

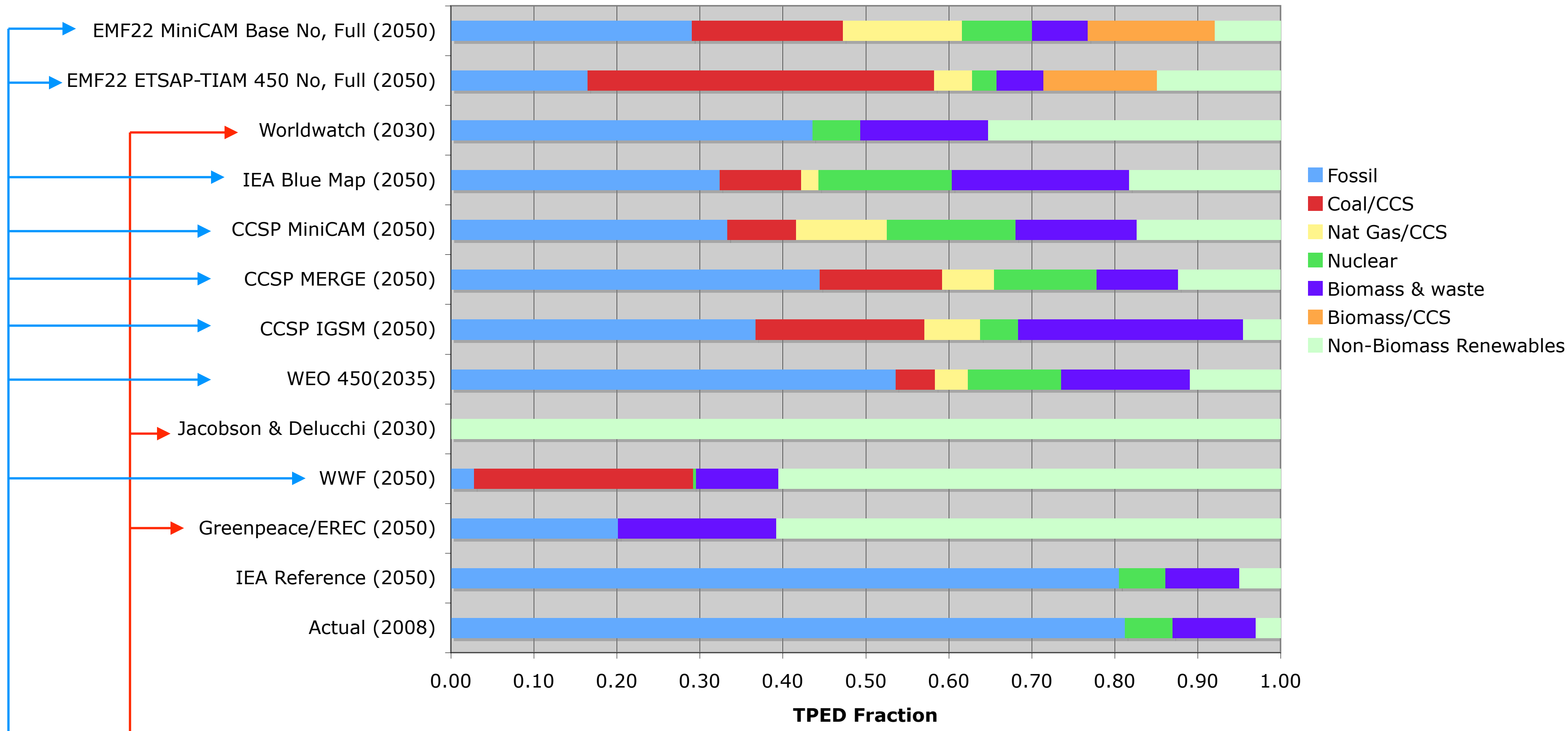


Implied Energy Intensity Reductions



- Projected TPED varies by a factor of ~2 in these scenarios.
- Demand reductions of 30 - 40 % relative to BAU projections are common.
- Again, implied energy intensity reductions required to meet these projections are much higher than historical values.

Projected Total Primary Energy Mix

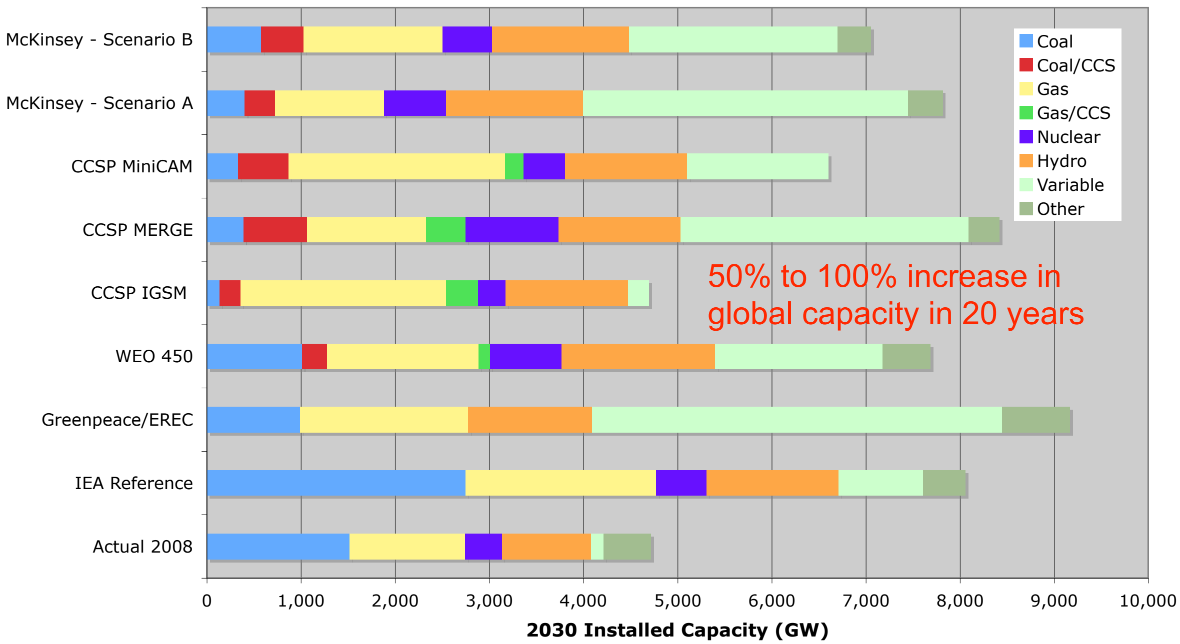


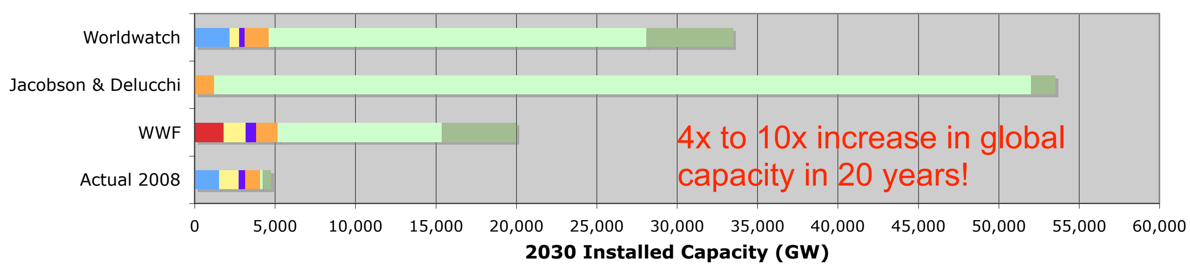
- Large demand reduction
- Heavy reliance on renewables
- Massive electrification
- Exclusion of key baseload technologies

- All options included in varying proportions

	TPED 2008	Range of Projections 2030 - 2050
Fossil	81%	0% - 54%
CCS	0%	0% - 60%
Nuclear	6%	0% - 16%
Renewables	3%	5% - 100%
Biomass	10%	0% - 27%

Projected Installed Power Generation Capacity in 2030





"Variable" includes wind and solar.
"Other" includes oil, biomass, geothermal and ocean.

- Power generation options are a primary focus of all of the studies, with much less detailed consideration given to other sectors.
- Most call for 50 - 100 percent increase in global capacity by 2030, adding 3,000 - 5,000 GW over 20 years.
- Renewables-heavy studies which exclude nuclear and/or CCS project a 4- to 10-fold increase, adding 20,000 - 50,000 GW in 20 years.
- This huge capacity addition is required for two reasons:
  - Wholescale electrification of the economy is assumed.
  - Inherently low capacity factors of wind and solar.

Required Rates of Capacity Addition

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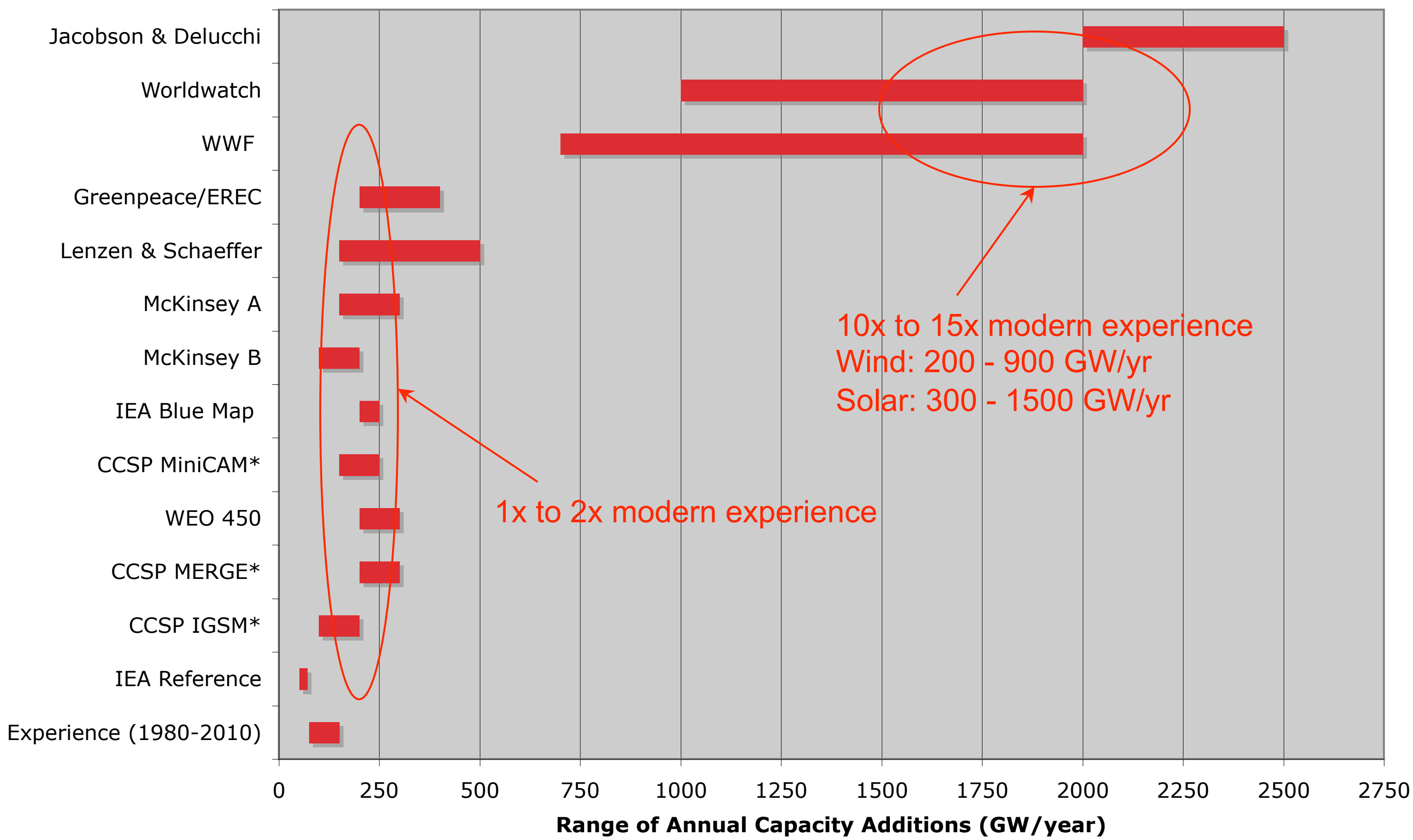

- Global capacity additions from 1980 - 2010 have varied from ~75 to ~150 GW per year.
- The WWF, Worldwatch and Jacobson & Delucchi studies call for order of magnitude increases over this rate - an enormous departure from experience.

Individual Technology Deployments

Indicates historical experience

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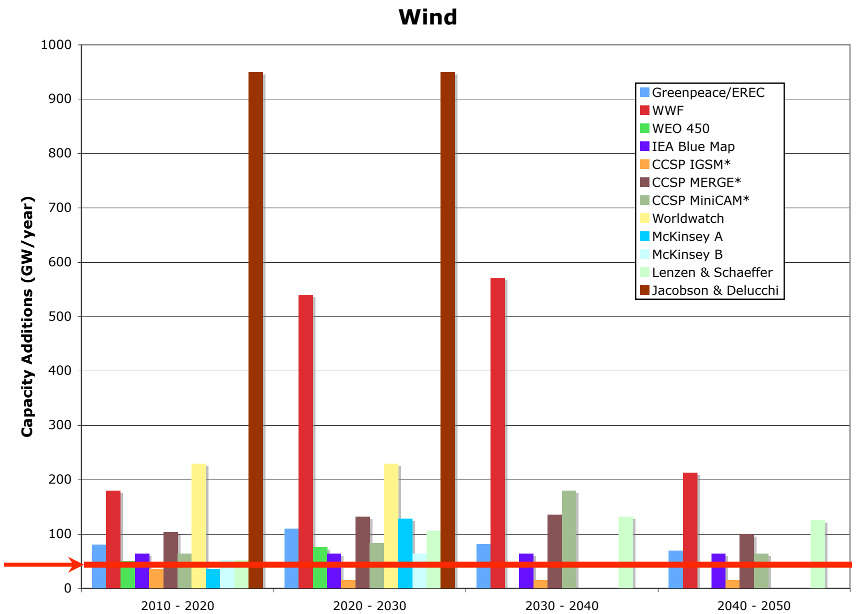
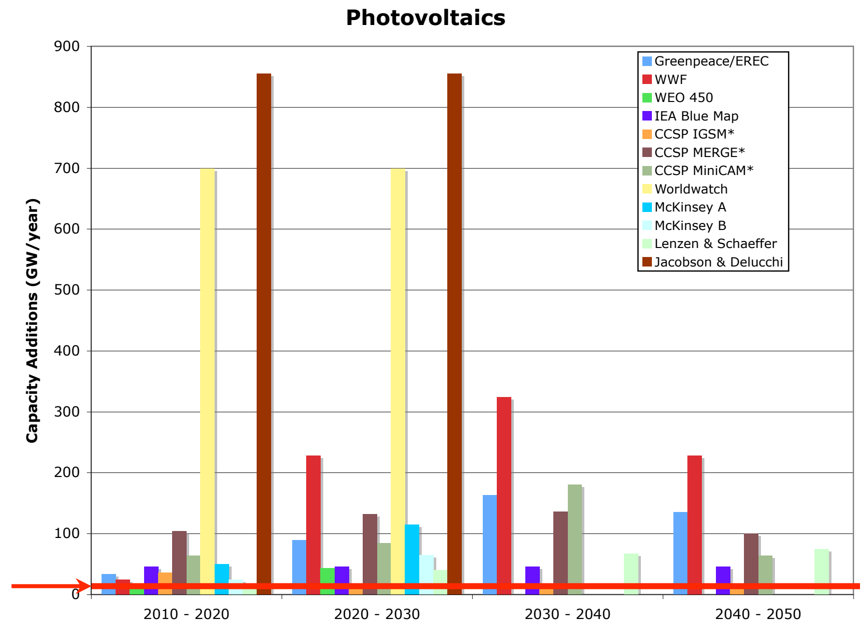
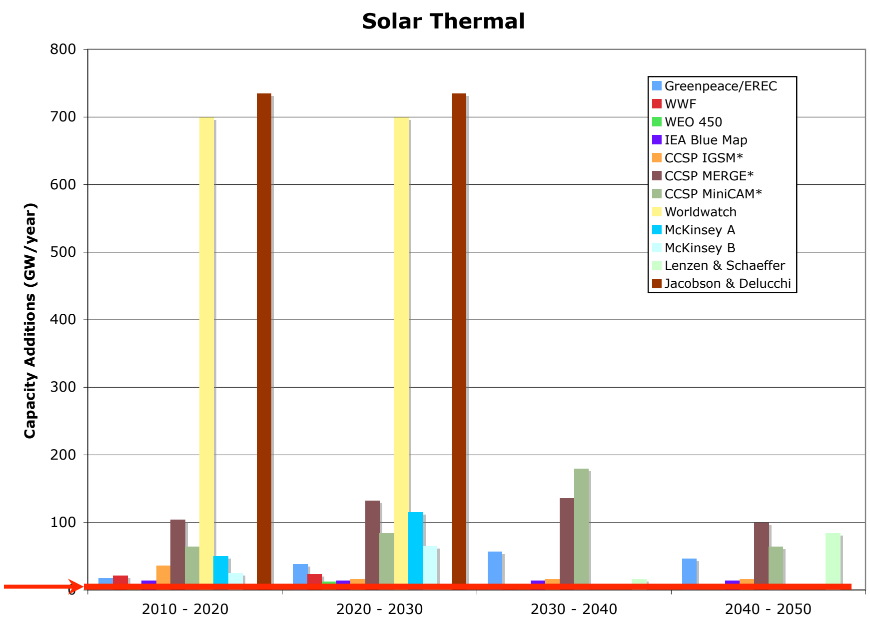
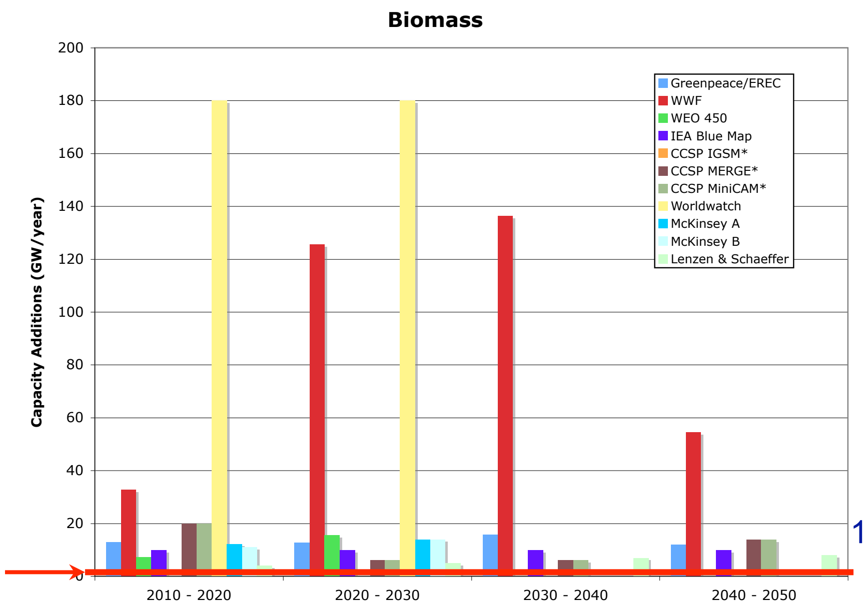


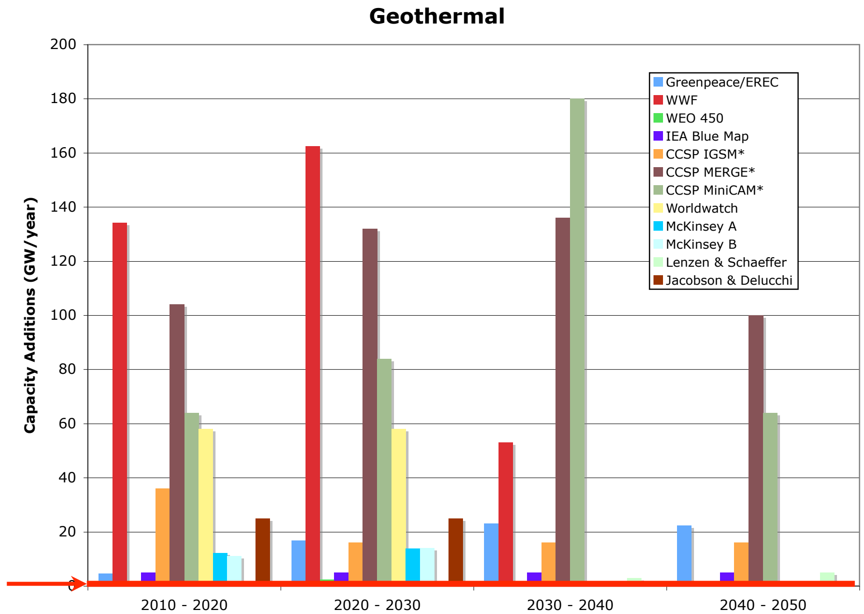


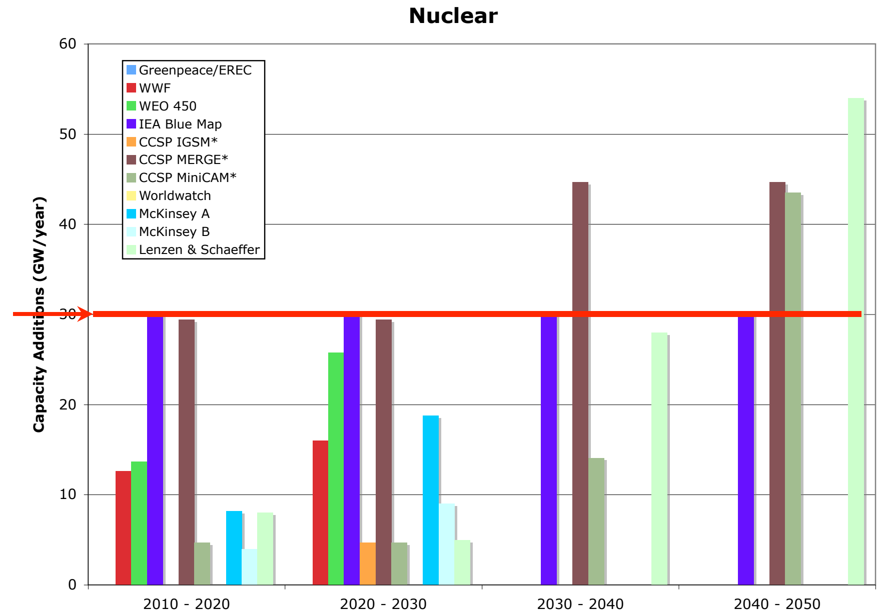


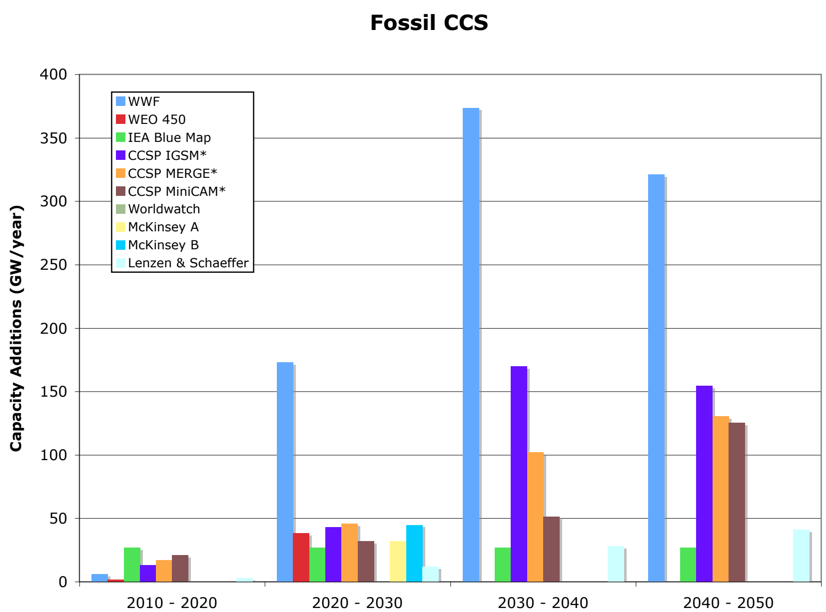


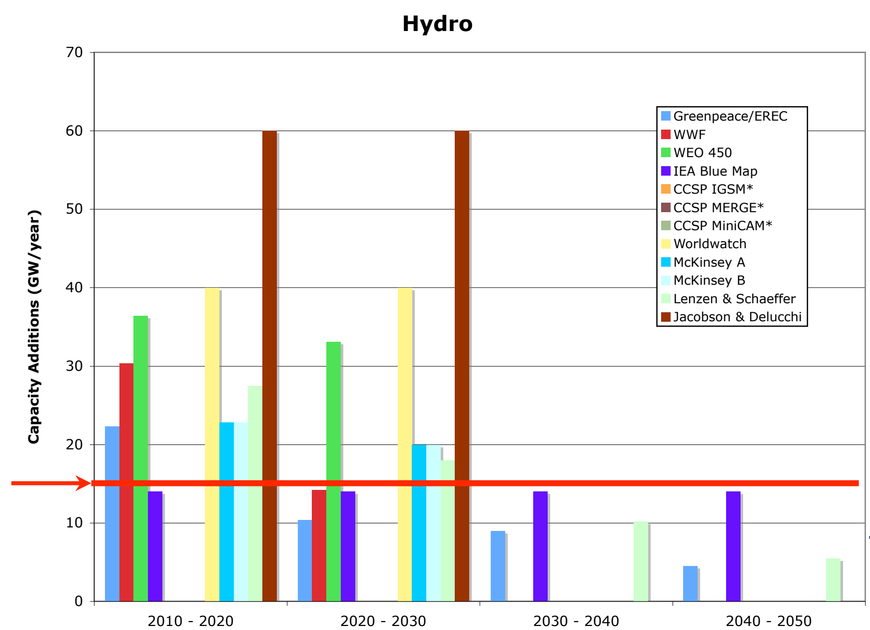
Individual Technology Deployments

Indicates historical experience









These three studies stand out from the group:

- “Conventional” renewable capacity additions FAR beyond experience:
  - Wind: 200 - 900 GW/year (cf. 40 GW installed in 2010)
  - Solar: 300 - 1500 GW/year (cf. 15 GW installed in 2010)
- Rapid implemention at scale of other currently-marginal renewables:
  - Geothermal power: 500 - 3000 GW installed by 2030 (cf. 11 GW installed base in 2008)
  - Ocean power: 200 - 1000 GW installed by 2030 (cf. zero in 2008)
- Rejection of baseload options:
  - Nuclear: Jacobson & Delucchi (and also Greenpeace/EREC) specifically call for elimination of nuclear power from the global mix and Worldwatch call for no additional nuclear capacity to be built.
  - CCS: Jacobson & Delucchi, Worldwatch (and also Greenpeace/EREC) see no role for CCS.

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No study calls for an expansion of nuclear comparable to those suggested for wind, solar or geothermal, or even CCS.

- Nuclear currently accounts for ~6% TPED. The most aggressive expansion in this set of studies (CCSP MiniCAM) suggests nuclear provide ~16% of TPED in 2050.
- Range of capacity projected for 2030 is 300 - 1000 GW (cf. ~400 GW installed base in 2008).
- The rate of capacity addition required to meet these targets is modest and within the range that has been demonstrated.
- Jacobson & Delucchi and Greenpeace/EREC specifically call for elimination of nuclear power from the global mix and Worldwatch call for no additional nuclear capacity to be built.

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With the exception of Jacobson & Delucchi, specifics are few and far between here.

- Many of the plans call for integration of more than 20% variable power (on an energy basis), with Jacobson & Delucchi calling for 90% variable power by 2030 and Greenpeace calling for the same percentage by 2050.
- The studies acknowledge the integration challenges, in general, and invoke many of the same options:
  - "Smart grid"
  - Storage
  - Production of hydrogen
- Only WWF make reference to the likely need for significant gas capacity for firming.
- Only Jacobson & Delucchi make reference to the need for radically improved weather forecasting.
- In general, the discussions in this area are conceptual and contain few specifics. The exception here is Jacobson & Delucchi, who
  - Provide by far the most detailed and comprehensive overview of related work that has been done in the areas of integration of dispersed variable resources, storage, "smart" demand response, and vehicle-to-grid technologies.
  - Present cost estimates for transmission and storage related to the integration of large amounts of variable generation.
- J&D's cost estimates vary enormously depending on assumptions made
  - Transmission costs of \$0.003 to \$0.03/kWh
  - Storage costs of \$0.01 to \$0.26/kWh

Treatment of these important sectors generally pales beside the extensive discussion of power generation options.

- In general, many of the studies assume massive vehicle electrification by mid-century.
  - J&D assume by 2030 95% LDV electrification, 70% HDV electrification, 80% rail electrification
  - Worldwatch and Greenpeace/EREC assume 50% global fleet electrification by 2030
  - WWF assume hydrogen for all LDV by 2050
  - IEA Blue Map assumes 80% LDV are mix of EV, PHEV, and FCEV by 2050
- Treatment of industrial energy use is even skimpier than that of transportation.
  - Only McKinsey presents any detailed assessment of industrial energy options, with specific options identified for petroleum & gas, cement, iton & steel, and chemicals.
  - Jacobson & Delucchi call for widespread electrification of industrial energy.
  - CCSP and WWF propose widespread use of hydrogen as an industrial fuel.

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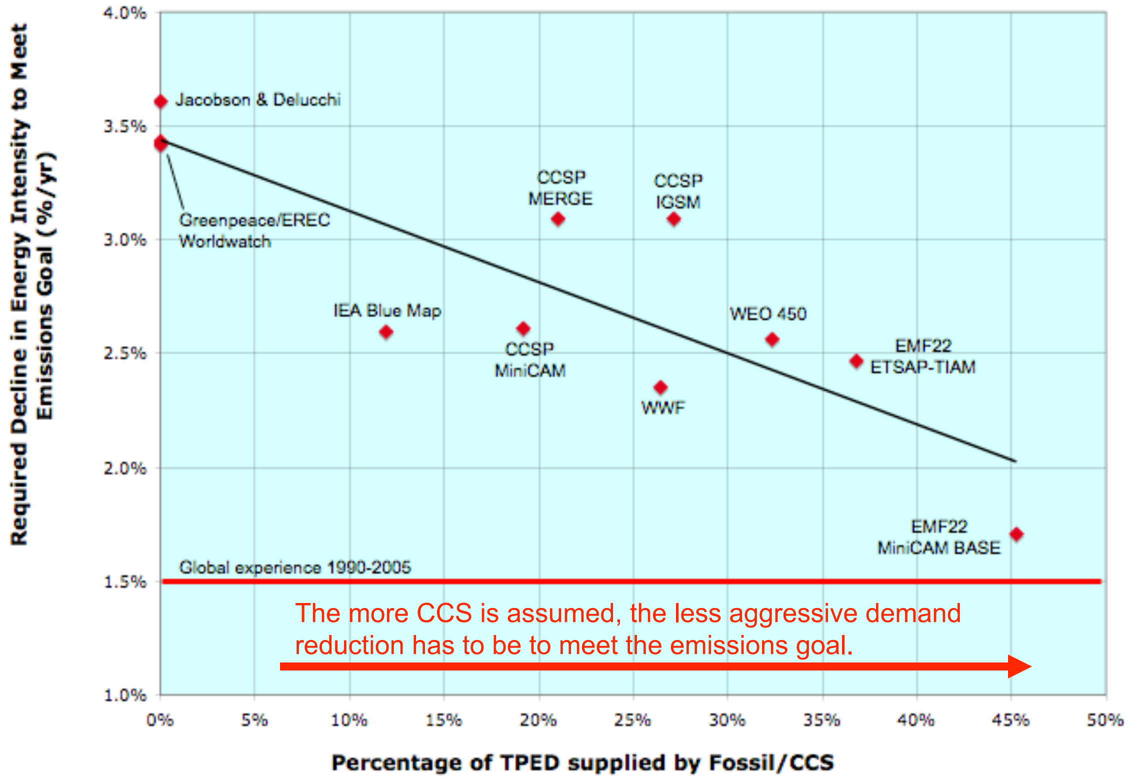
CCS is seen as a key option in almost all of the studies, with contributions ranging from 12 to 60% of TPED in 2050.

- Most studies assume a decade of demonstration and scale-up, with widespread deployment after 2020.
- Coal and gas CCS are envisioned, and in some studies biomass CCS is included.
- McKinsey and the IEA also envision CCS in energy-intensive industries such as cement, iron & steel, chemicals and pulp & paper.
- Implementation of CCS allows the attainment of more aggressive carbon reduction targets at lower aggregate cost, according to the CCSP studies.



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The volumes of CO_2 to be collected, compressed, transported and injected are large: so large that they can be compared to global oil and gas volumes.

- The range of CCS deployment after 2020 called for in these studies is 10 to 50 GW per year.
- Compare this annual increment in CO_2 to be collected, transported and injected to recent annual increments in oil or gas processing:
  - Recent annual increments in volume of oil extracted, transported and processed are equivalent to the annual liquid volume of compressed CO_2 from ~ 30 GW of coal capacity.
  - Recent annual increments in volume of gas extracted, transported and processed are equivalent to the annual gaseous volume of CO_2 from ~ 65 GW of coal capacity.
- So in terms of drilling and completing wells and installing compression and pipeline capacity, the deployment rates called for are within our general range of experience.

Conclusions

To have the best chance of meeting stringent emissions targets, no viable option which can be deployed at scale within the next decade should be taken off the table.

- **All plans**
  - call for a **major departure** from business-as-usual energy investment patterns.
  - require improvements in energy intensity **far beyond the historical** reduction of 1.5% per annum.
- **Most plans**
  - call for implementation of **all currently-available low-carbon options**, increasing deployment rates in the next decade to roughly two or three times historical aggregate deployments.
  - call for **CCS to play a key role**, ultimately in coal and gas power generation, as well as energy-intensive industries.
  - call for **modest nuclear expansion.**
- **Some plans**
  - call for radical departures, with **almost complete reliance on variable generation** (principally wind and solar), **wholesale electrification**, and **de-commissioning** of key baseload technologies.
  - resulting deployment rates for renewables are **orders of magnitude** greater than experience.
  - likely integration issues are **immense**.

Given the entrenched nature of fossil fuels in our energy system, avoiding the use of CCS makes a difficult task almost impossible.