Summary of IEA Socio-Economic Workshop Culham, UK, 25-27 April 05

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The Boeing Company

ARIES Meeting
University of Wisconsin, Madison
14-15 June 2005

BOEING

Purpose of Workshop

The purpose of the workshop was to gather, present, discuss, and derive a view of the Socio-Economic aspects of fusion. The outcome of this workshop will be a consensus opinion for the workshop participating countries and regions, principally the EU, Japan, US, and China.

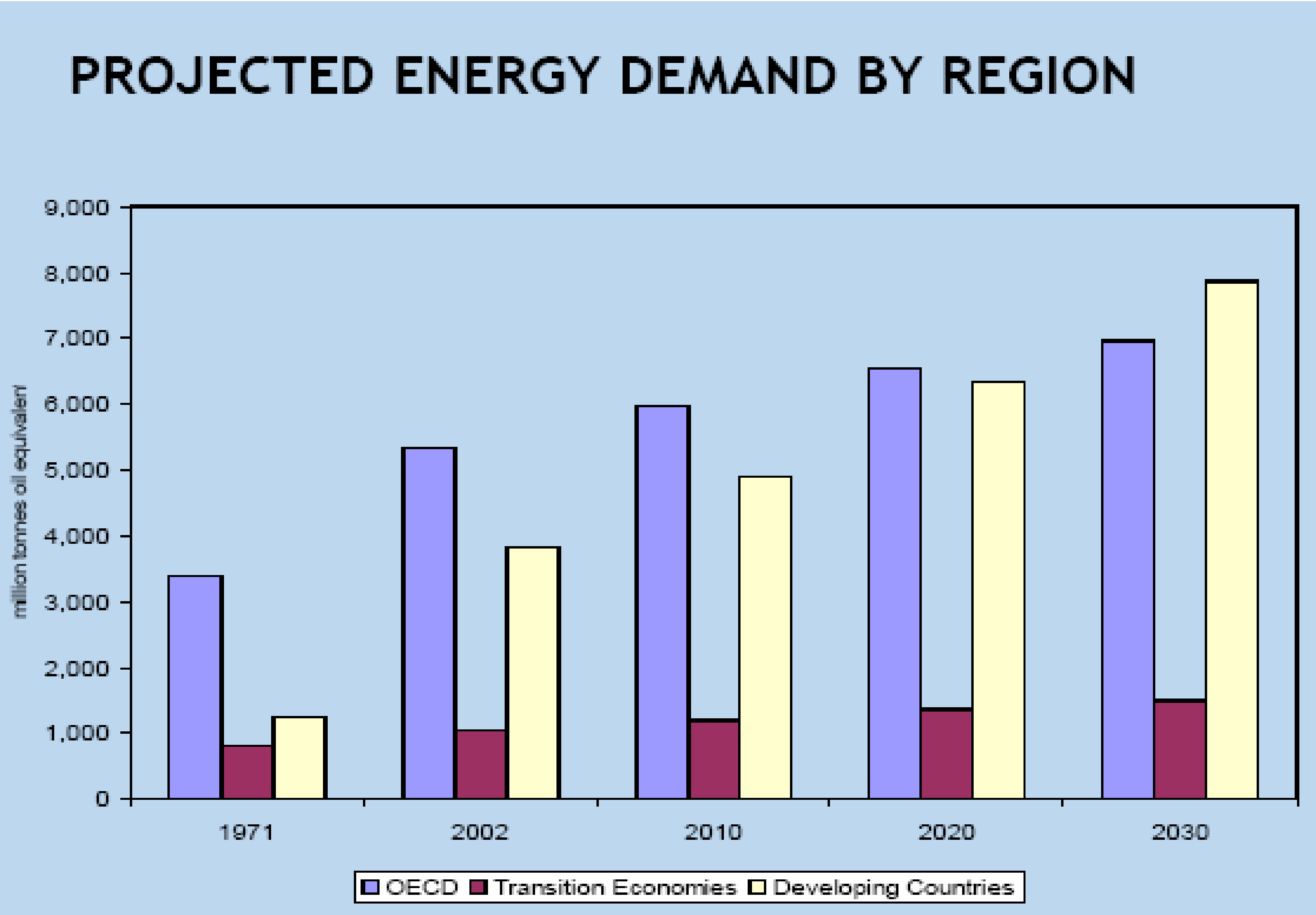
Participating Regions	Attendees
United States	J. Kulcinski, F. Najmabadi, J. Schmidt, L.Waganer
Japan	S. Konishi
China	J. K. Xie
EU	I. Cook, D. Ward, and many other participants (~16)

- **Link to Workshop agenda and presentations at www.fusion.org.uk/socioecon**
- **Summary of Workshop by Ian Cook can be found in June issue of ANS-FED newsletter, http://aries.ucsd.edu/ANS/newsletters.shtml**

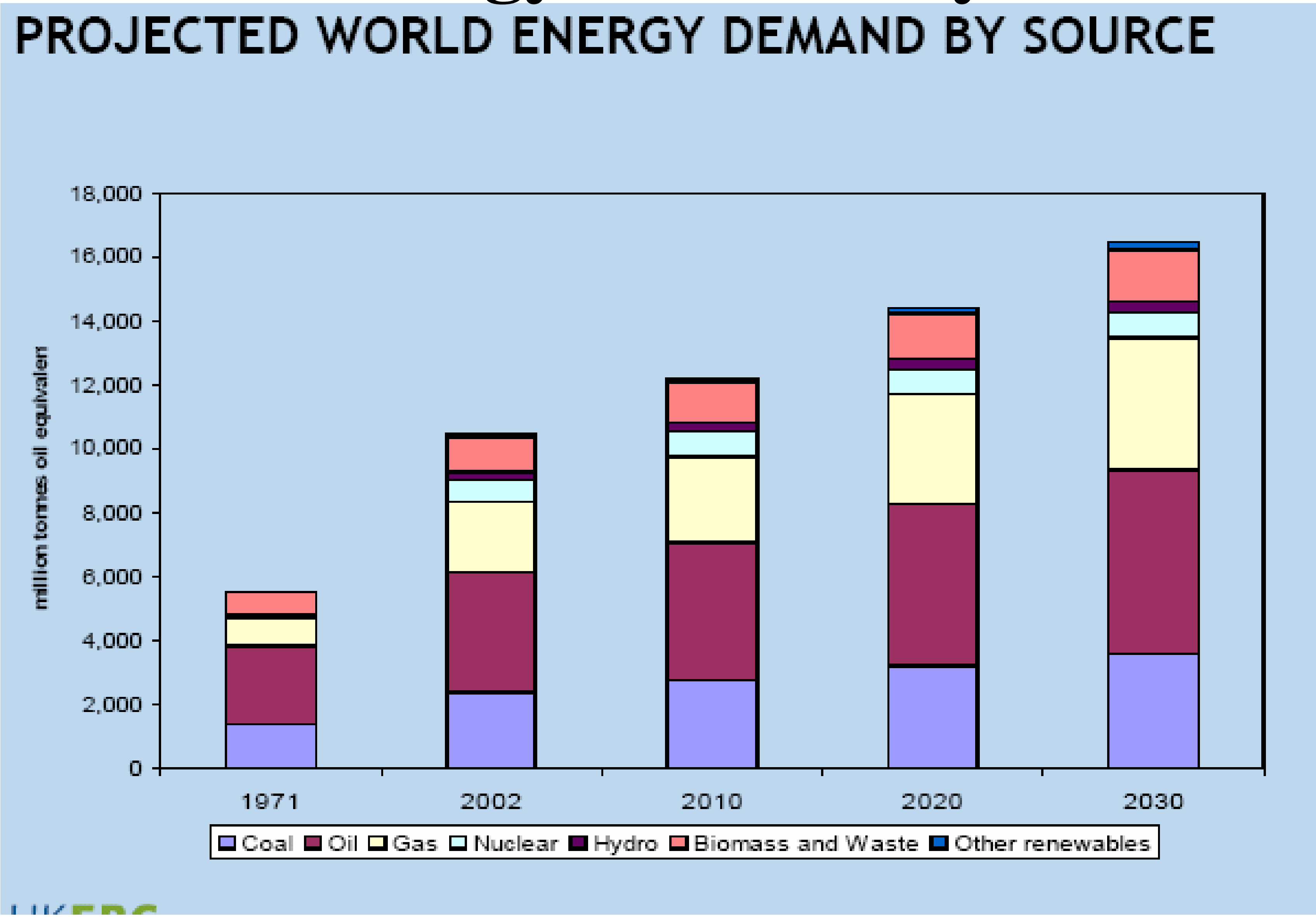
General Topics of Discussion

- Predicted Energy Demand
- World Energy Historical and Predicted Usage
- Natural Resource Limitations (Fossil and Fissile)
- Capabilities of Renewable Energy Sources
- Major Energy Generation Capabilities
- Electrical Energy Storage
- Alternate, Non-Electricity Production
- Internal and External Cost of Electricity

Predicted Energy Demand



Predicted Energy Demand by Source



Ref: J. Skea, "The Energy Challenge"

China Energy Consumption Estimate

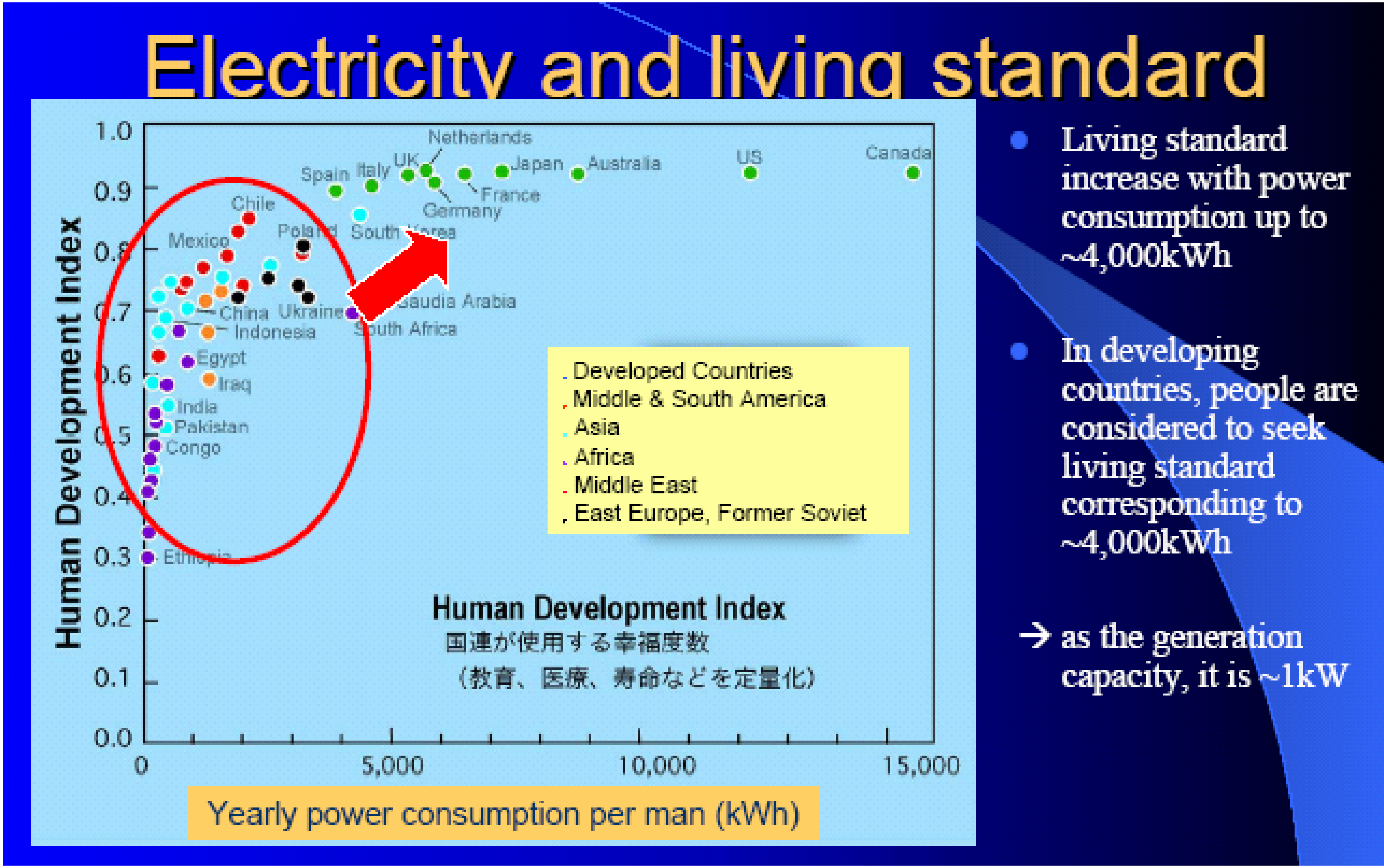
	Energy needs (B.ton Coal Equiv.)	Electricity (GW)	Nuclear elec. (GW)
2000	1.5	300	4
2020	3	600	30-40
2050	4	800-1000	80-100

Ref: J. Xie, "China View of Fusion Energy"

Everybody has a TV and they will feel they are entitled to have the "good life."

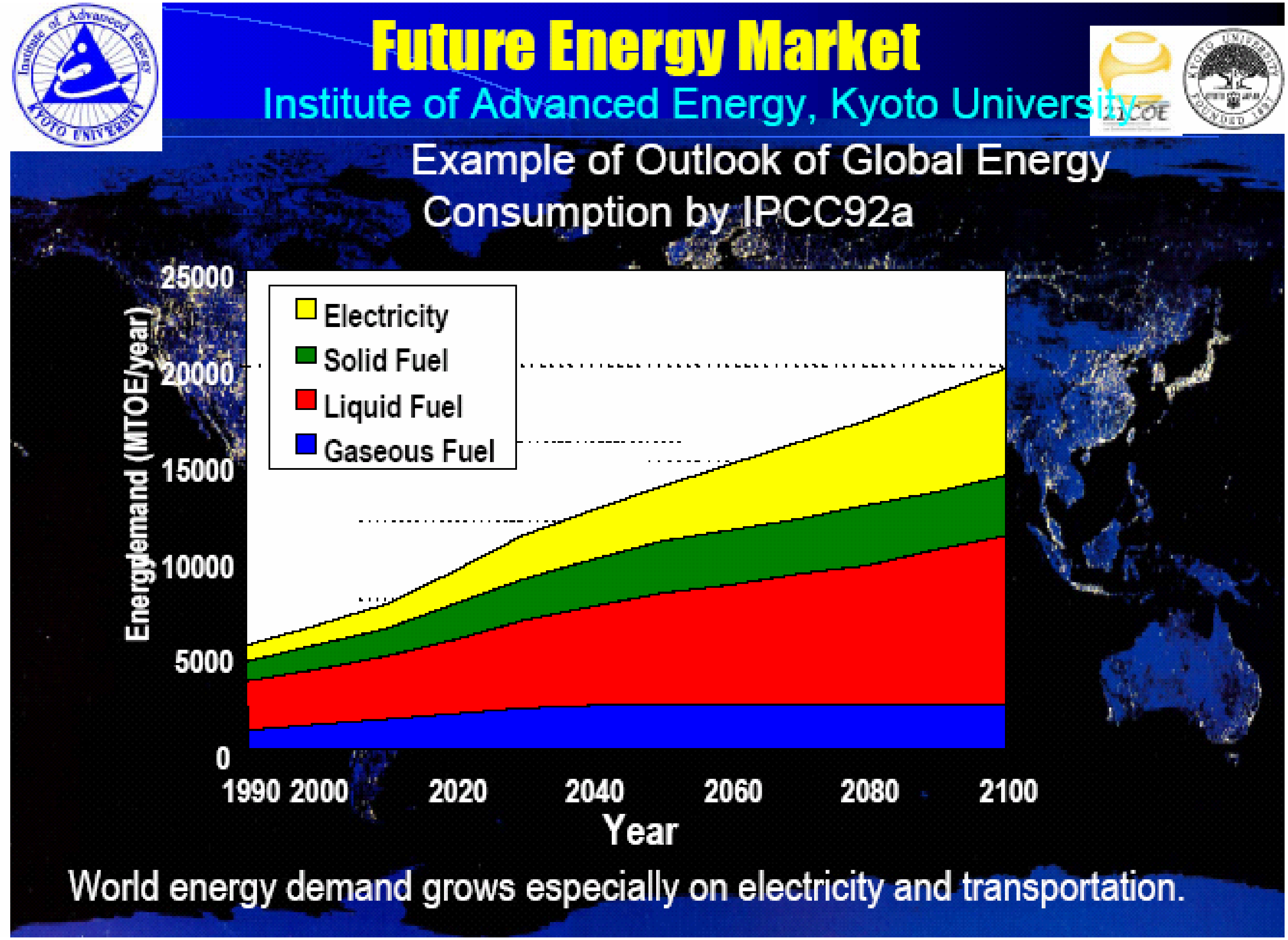
- **Refrigerators**
- **Air Conditioners**
- **Cars**
- **Bigger Houses**
- **Computers**
- **Entertainment Centers**
- **Boats**
- **Etc**

Link Between Standard of Living and Energy



Ref: S. Konishi and Y. Yamamoto, “Socio-Economic Considerations of Fusion in Japan’

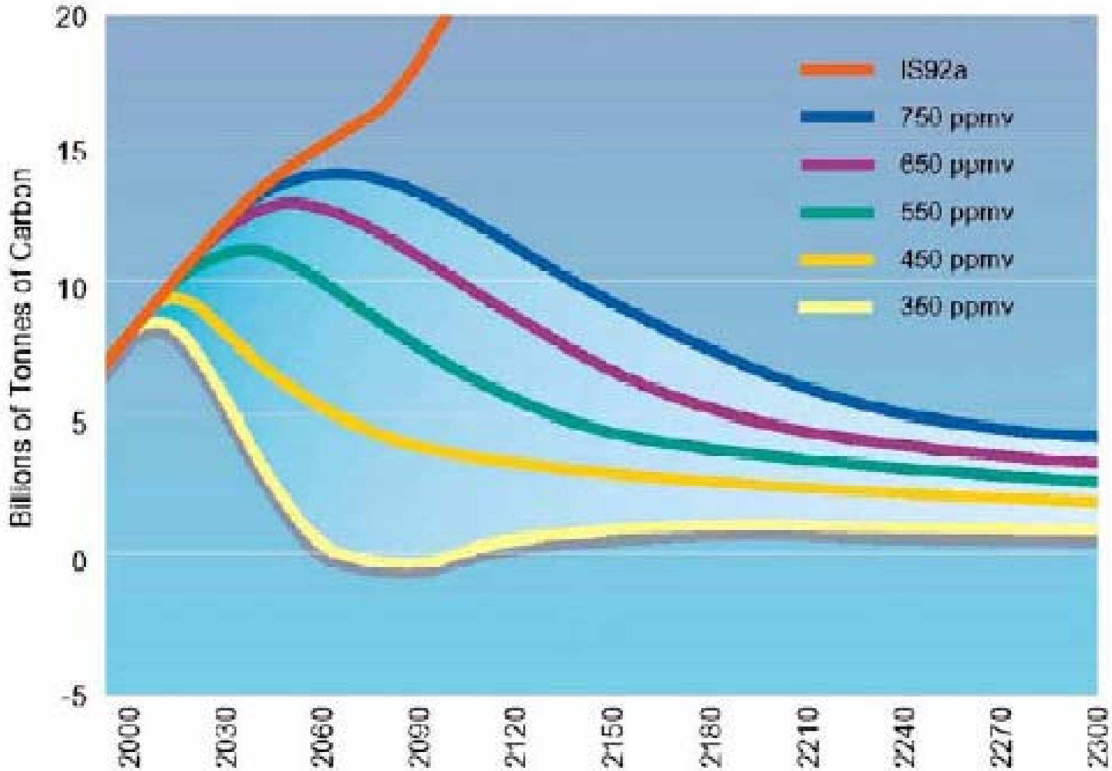
Japan's Energy Forecast



Ref: S. Konishi and Y. Yamamoto, "Socio-Economic Considerations of Fusion in Japan"

EU Goal is 60% Reduction by 2050

Must Use Carbon Capture and Storage + Nuclear Power

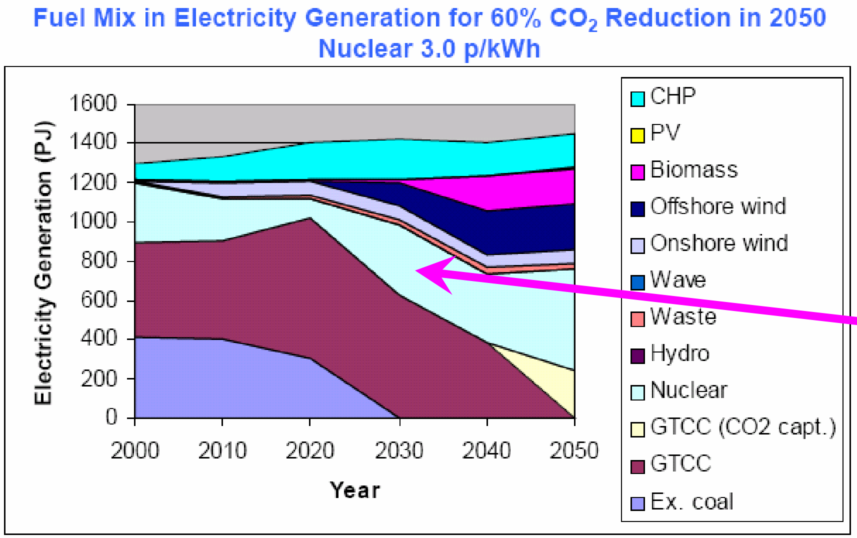


Emission trajectories consistent with various atmospheric CO2 concentration ceilings
(J. Edward, NREL Energy Analysis Forum, Understanding the U.S. Strategic Interests in Expanding Renewable Energy Systems Worldwide, Washington, DC, June 11-12, 2003. http://www.nrel.gov/analysis/forum/docs/jae_edmonds.2.ppt)

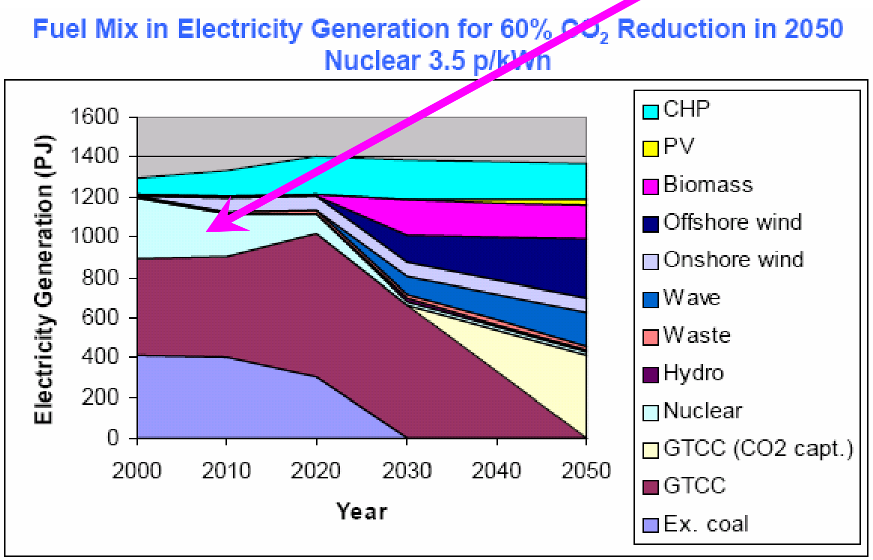
CCS adds an Extra ~ 0.5-2p/kWh (~ 1-4 ¢/kWh)

Ref: J. Gibbons, "Carbon Capture and Storage – A Bridge to Fusion?"

EU Electricity Generation with CCS



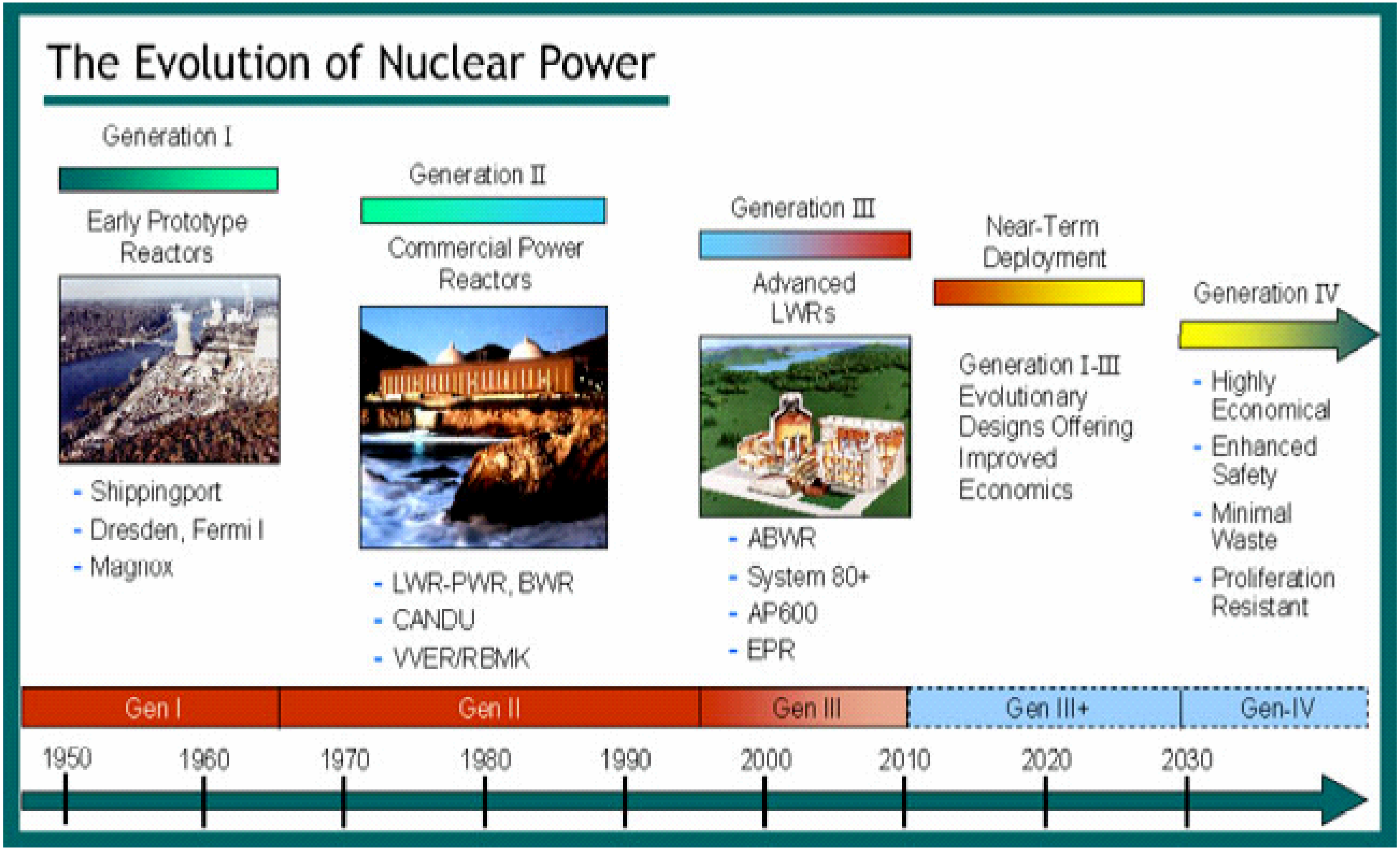
This model shows use of nuclear is very sensitive to the COE (3.0 p/kWh vs 3.5 p/kWh)



Ref: J. Gibbons, "Carbon Capture and Storage – A Bridge to Fusion?"

Fission Roadmap

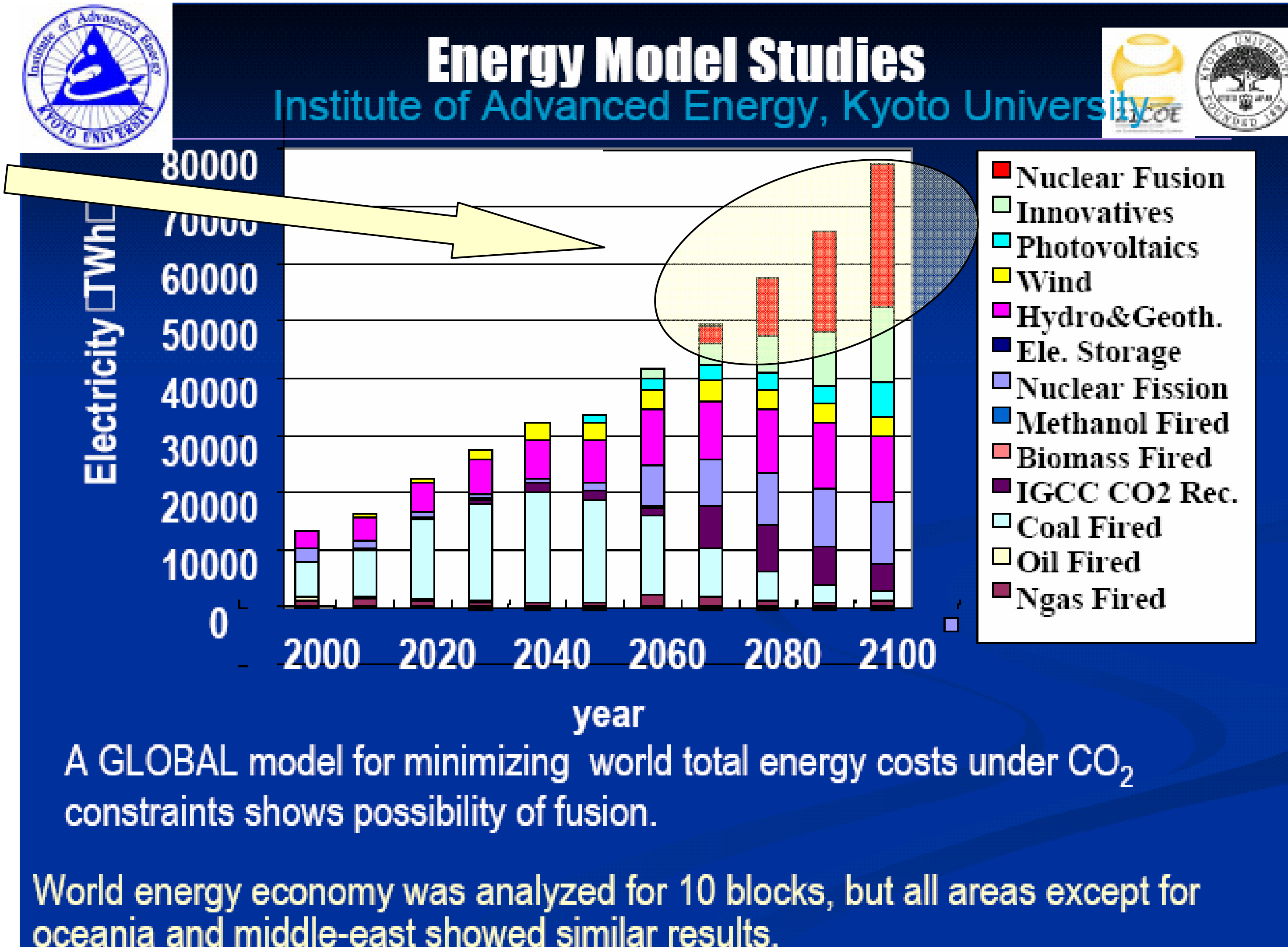
Ref: P. Howarth, "Future Prospects for Nuclear Fission Energy Technology"



Japanese Electricity Generation Model

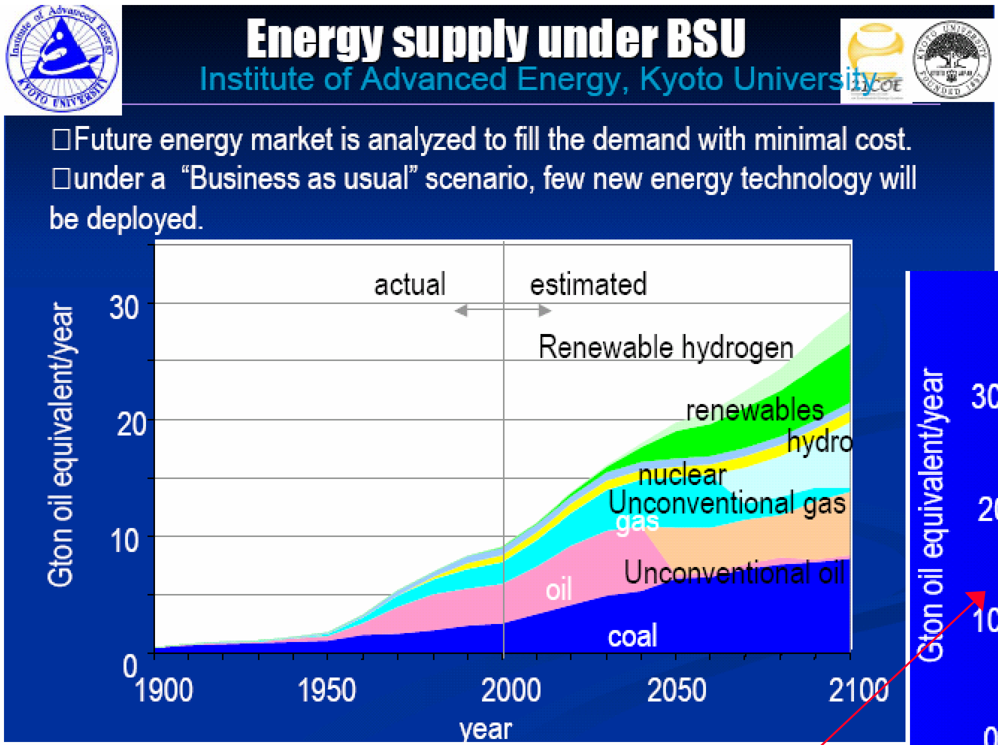
Fusion contributes after 2060

Ref: S. Konishi and Y. Yamamoto, "Socio-Economic Considerations of Fusion in Japan"

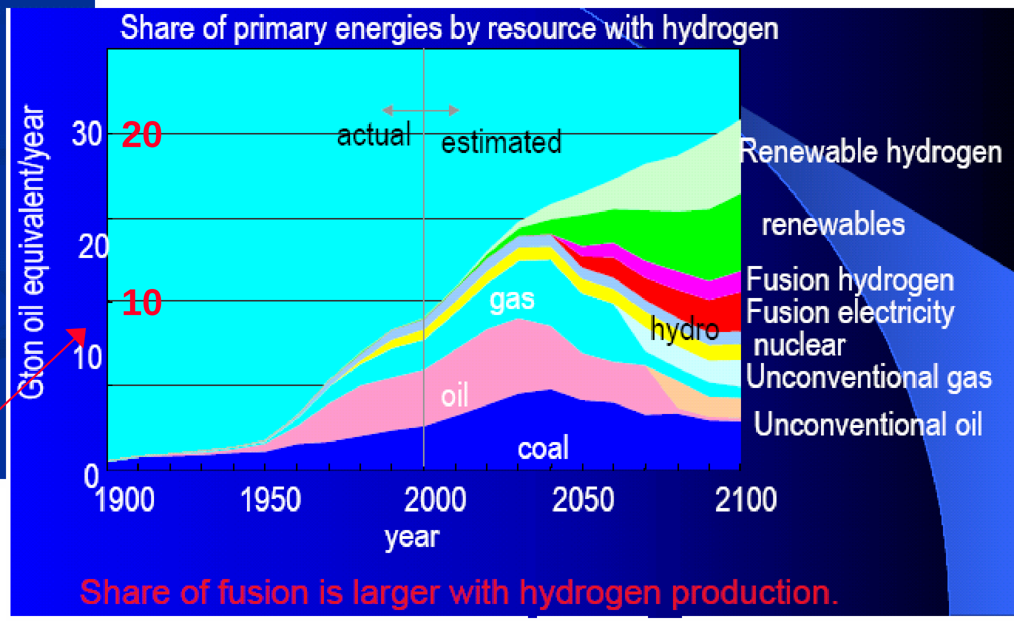


Japanese Energy Generation Model

Business As Usual



Market Driven by Resource and Environmental Constraints

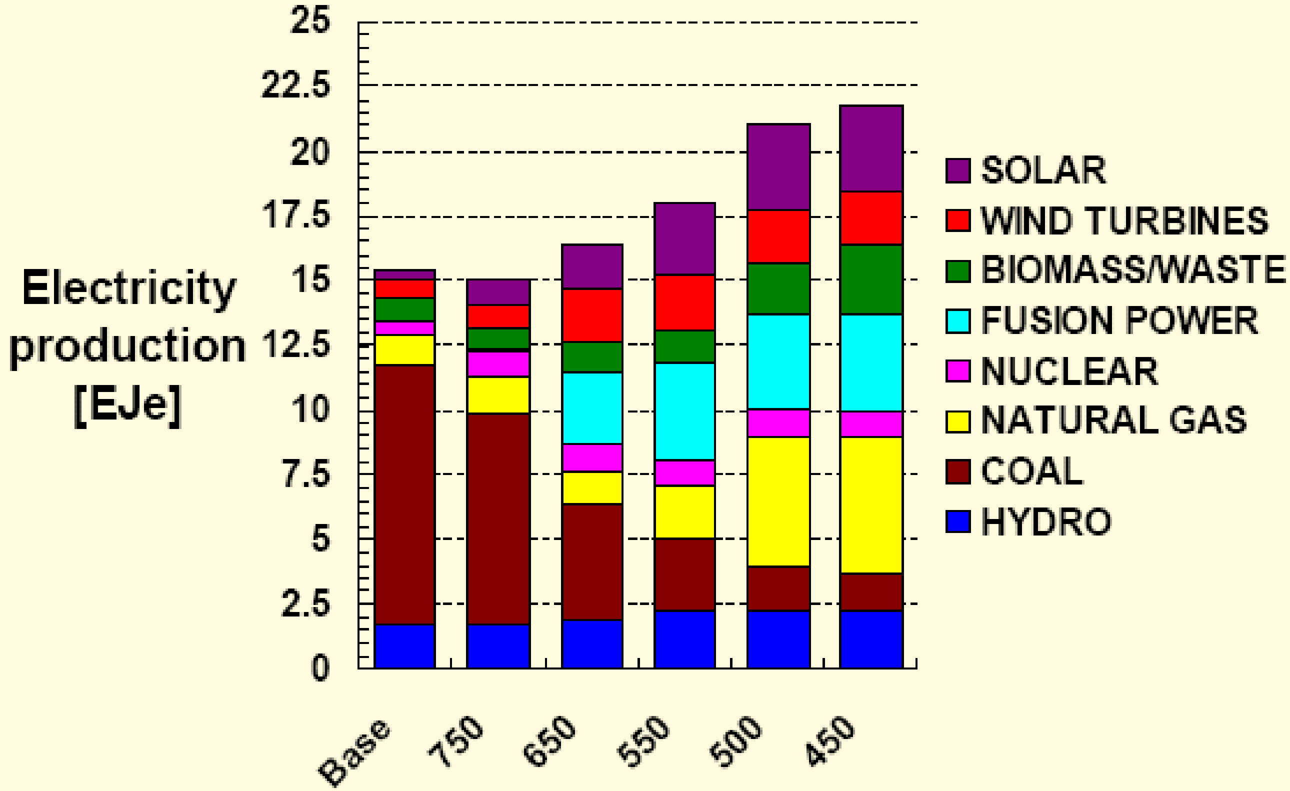


Ref: S. Konishi and Y. Yamamoto, "Socio-Economic Considerations of Fusion in Japan"

I suspect the ordinate grid is incorrect

CO^2 Limits Affect Renewables, Fusion and Natural Gas

Scenario variants with various CO_2 limits, MD, 2100

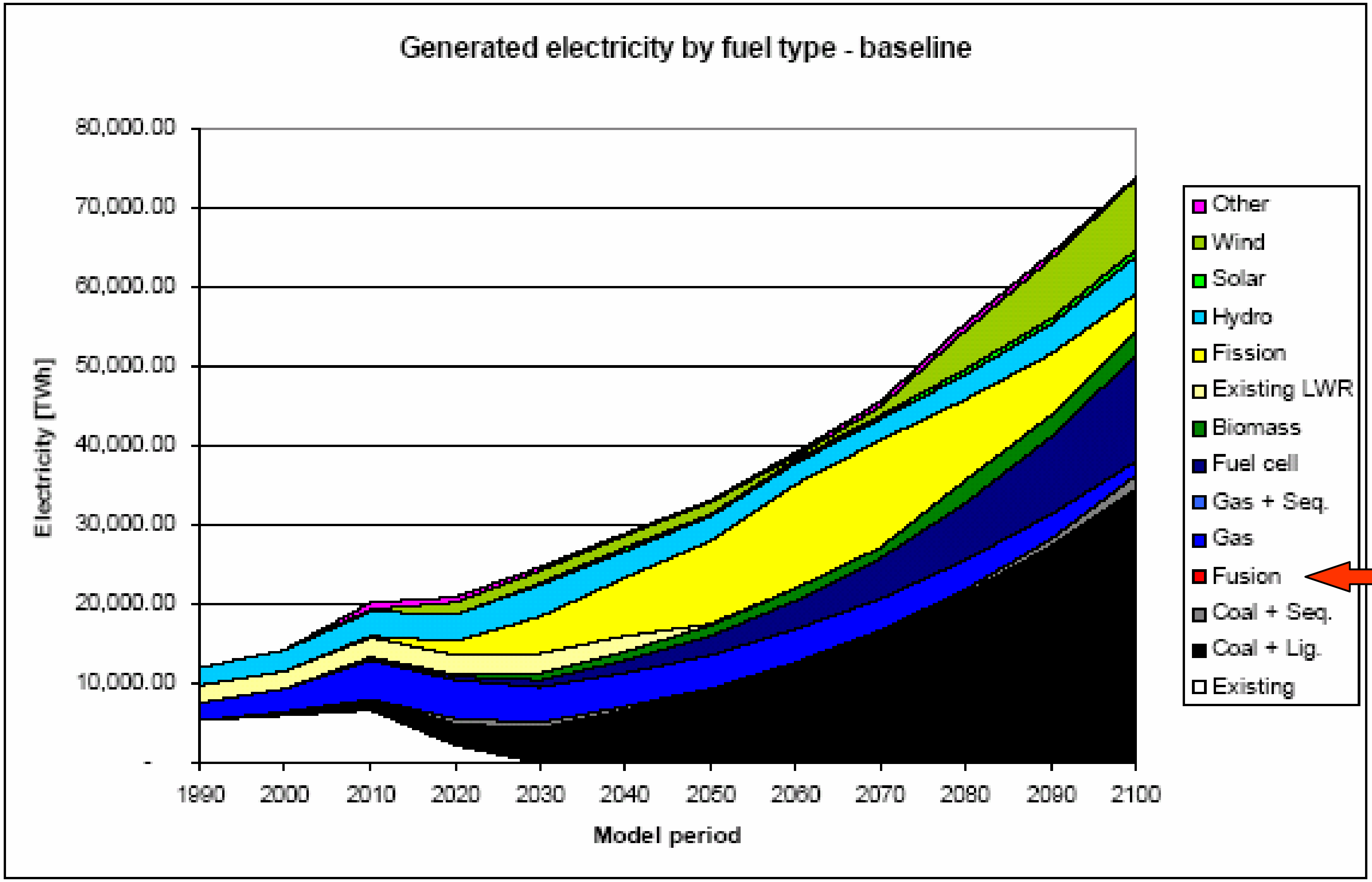


Ref: P. Lako, "Long-Term Potential of Fusion Power in Western Europe"

Baseline Electricity Forecast

Recent long-term scenario results with the TUG-IPP global single-regional energy model – I

(Ref Max Plank Institute/Institute of Theoretical and Computational Physics)



Fusion not a player in this scenario

Ref: C. Eherer, "Recent long-term scenario results with the TUG-IPP global single-regional energy model – I"

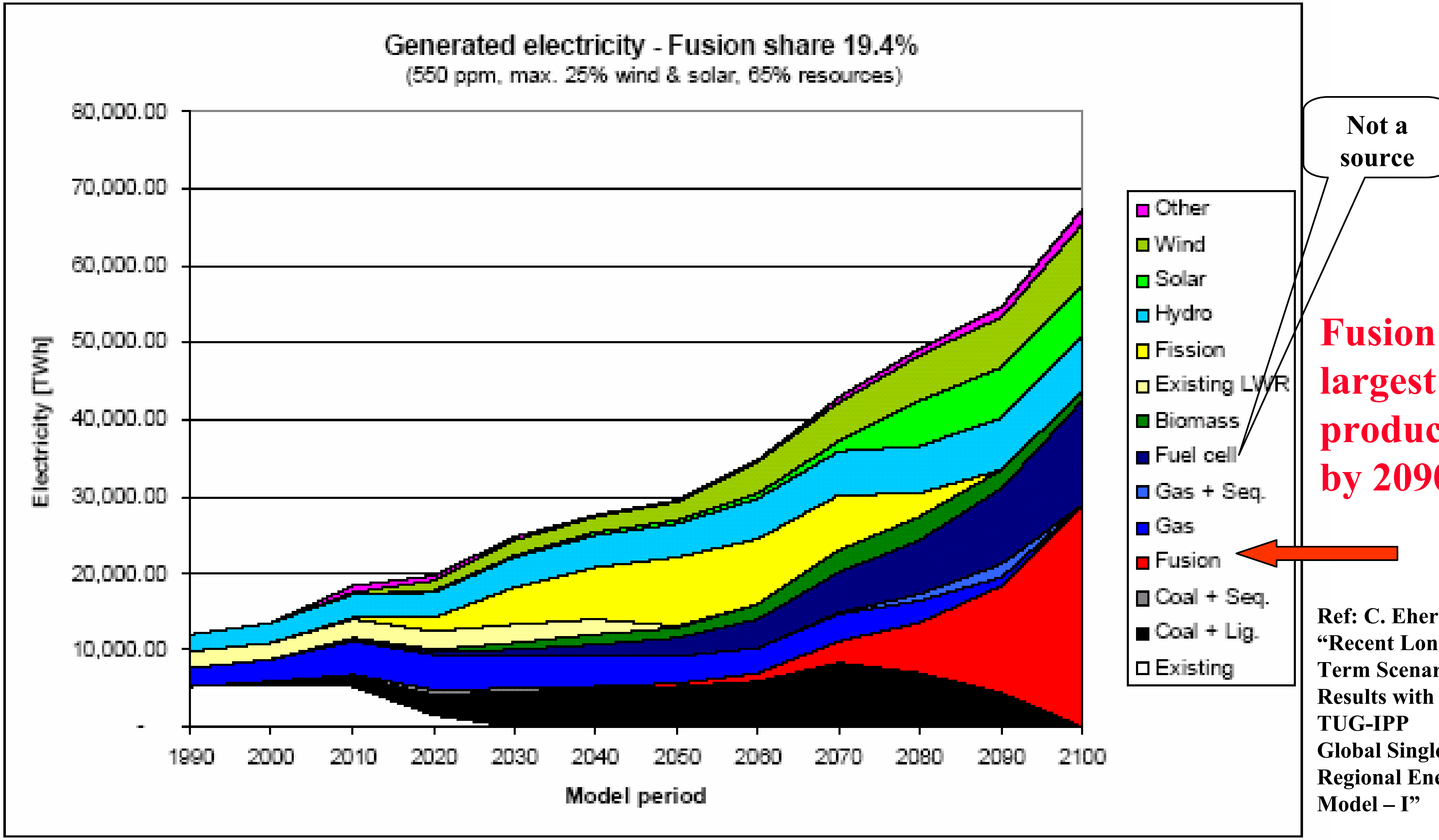
Boundary conditions for fusion power in the TUG-IPP model

- Fusion power does not enter the solution, if GEN IV liquid metal fast breeders are available
- Fusion power is favoured by constrained CO2 emissions
- Fusion power is favoured by lower availability of resources (coal, gas, oil, uranium)
- Fusion power is favoured by lower shares of solar power and wind power, although high shares of renewables are not excluding fusion power from the system – fusion power and renewables can coexist
- Limits on the maximum amount of CO^2 sequestration have no impact on the role of fusion power

Ref: C. Eherer, "Recent long-term scenario results with the TUG-IPP global single-regional energy model – I"

Baseline Electricity Forecast

with Constraints on CO^2, Renewables, and Resources



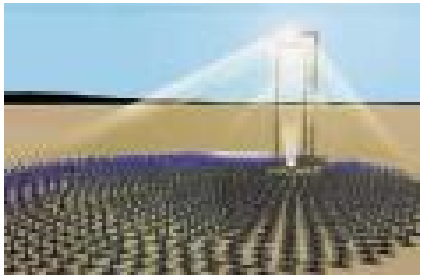
Fusion is largest producer by 2090

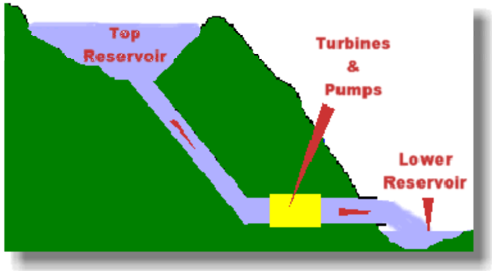
Ref: C. Eherer, "Recent Long-Term Scenario Results with the TUG-IPP Global Single-Regional Energy Model – I"

Electrical Energy Storage

- These sources are limited to certain geographical regions
- Periodic renewable energy sources, such as Solar, Wind, and Tidal, are limited to peaking demands, unless they are supplemented with storage systems.

- Adding storage capability significantly increases their COE, decreasing competitiveness
- Pumped storage (hydraulic or pneumatic) appeared to be the best
- Spinning electrical grid capacity and hydrogen storage can be forms of energy storage



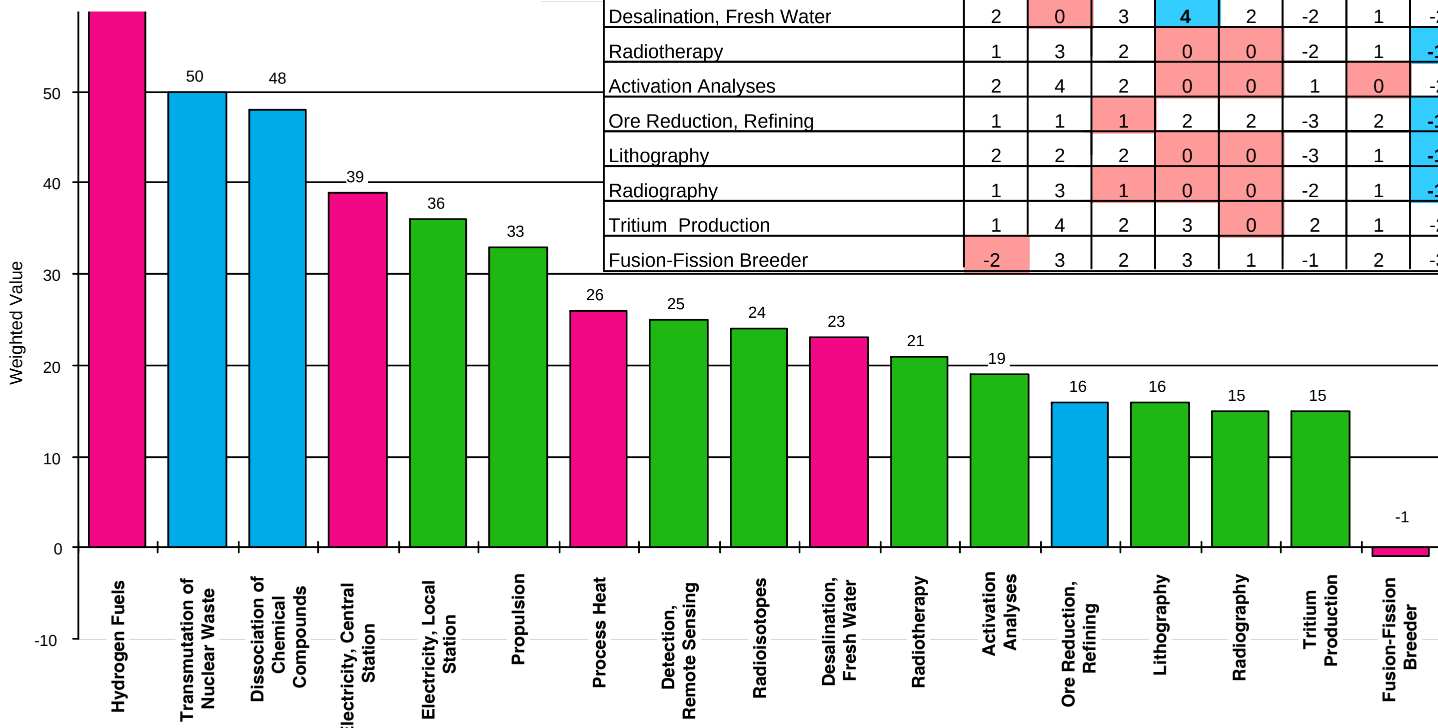
Hydrogen Production with Fusion May Have More Market Potential Than Electricity Production

Attribute Scores for Fusion Products

Products / Attributes	Necessity	Uniqueness	Market Potential	Resources	Environment	Competitive	Helps GNP	Investment	Technical Maturity	Time to Market	Prestige	Public Support	Weighted Sum
Weight	3	3	3	3	3	2	1	2	2	2	3	3	±145
Hydrogen Fuels	3	4	4	4	5	-2	4	-4	-4	-4	4	4	60
Transmutation of Nuclear Waste	2	4	4	1	4	0	2	-2	-2	-2	3	2	50
Dissociation of Chemical Compounds	2	3	3	1	5	-2	2	-1	-2	-2	2	4	48
Electricity, Central Station	2	2	3	3	4	-2	3	-4	-3	-3	3	3	39
Electricity, Local Station	1	2	2	2	4	-4	2	-2	-2	-2	3	4	36
Propulsion	1	5	2	0	0	2	1	-3	-2	-2	4	2	33
Process Heat	1	1	1	2	4	-1	3	-3	-2	-2	2	2	26
Detection, Remote Sensing	2	3	3	0	0	1	1	-1	-1	-2	1	1	25
Radioisotopes	2	2	2	1	0	-2	1	-1	-1	-1	1	3	24
Desalination, Fresh Water	2	0	3	4	2	-2	1	-2	-3	-3	2	1	23
Radiotherapy	1	3	2	0	0	-2	1	-1	-1	-1	1	3	21
Activation Analyses	2	4	2	0	0	1	0	-2	-2	-1	1	0	19
Ore Reduction, Refining	1	1	1	2	2	-3	2	-1	-2	-2	1	2	16
Lithography	2	2	2	0	0	-3	1	-1	-1	-1	1	2	16
Radiography	1	3	1	0	0	-2	1	-1	-1	-1	1	2	15
Tritium Production	1	4	2	3	0	2	1	-2	-3	-2	-1	-1	15
Fusion-Fission Breeder	-2	3	2	3	1	-1	2	-3	-4	-4	1	-1	-1

Color Coding Key
Highest Score for Attribute
Lowest Score for Attribute

Colored Bars Denote Potentially Similar Fusion Plants



Relative Ranking of Fusion Products

Ref: L. Waganer, "Socially and Economically Attractive Non-Electric Applications for Fusion"

Internal and External Cost of Electricity

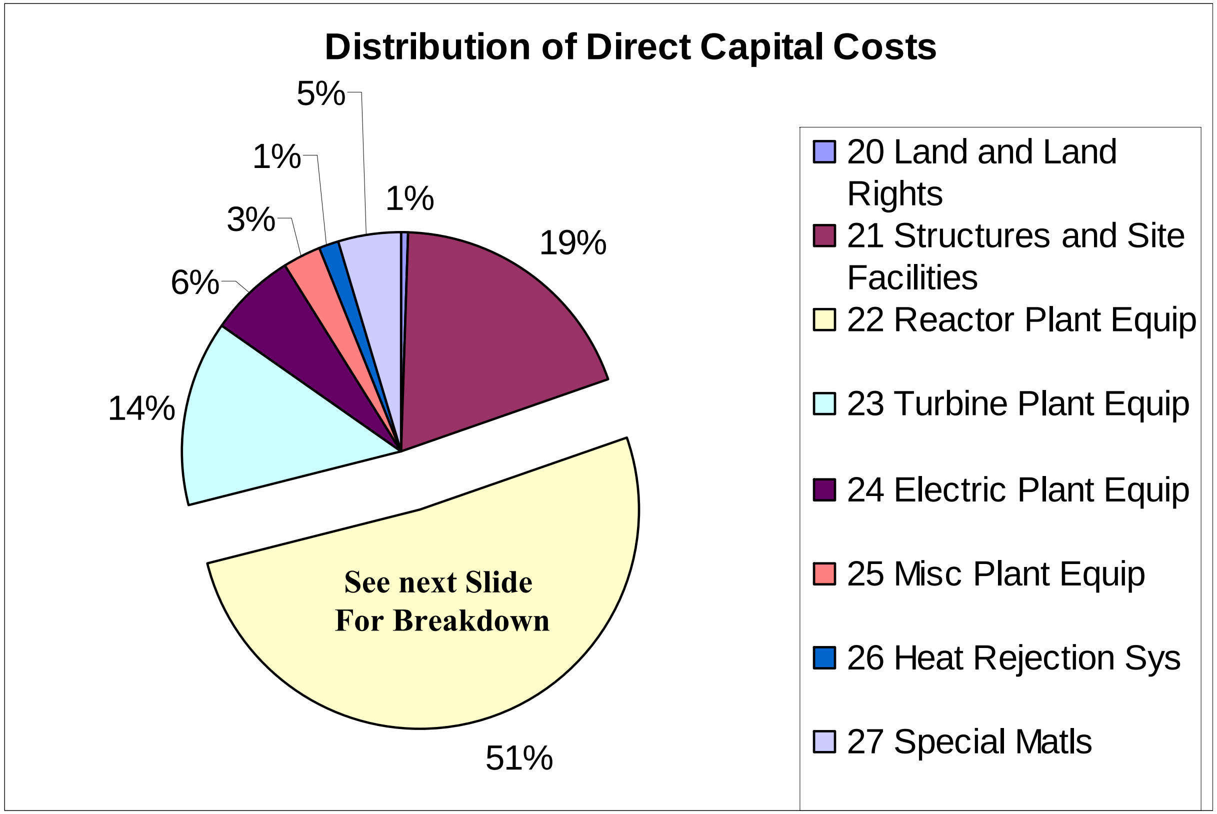
"Internal costs" are the contributions to the cost of electricity from constructing (direct and indirect), fuelling, scheduled maintenance, operating, and disposing of, power stations

In addition to the internal costs, there are also "external costs", and "shadow costs" associated with constraints.

- External costs are those associated with environmental damage or adverse impacts upon public and worker health.
- A methodology for evaluating external costs of electricity generation was developed for Europe and used to evaluate the external costs of a variety of electricity sources.
- Has also been used to evaluate the external costs of fusion electricity in Europe.

What Capital Cost Elements of COE Can Be Influenced?

ARIES-AT is a typical example



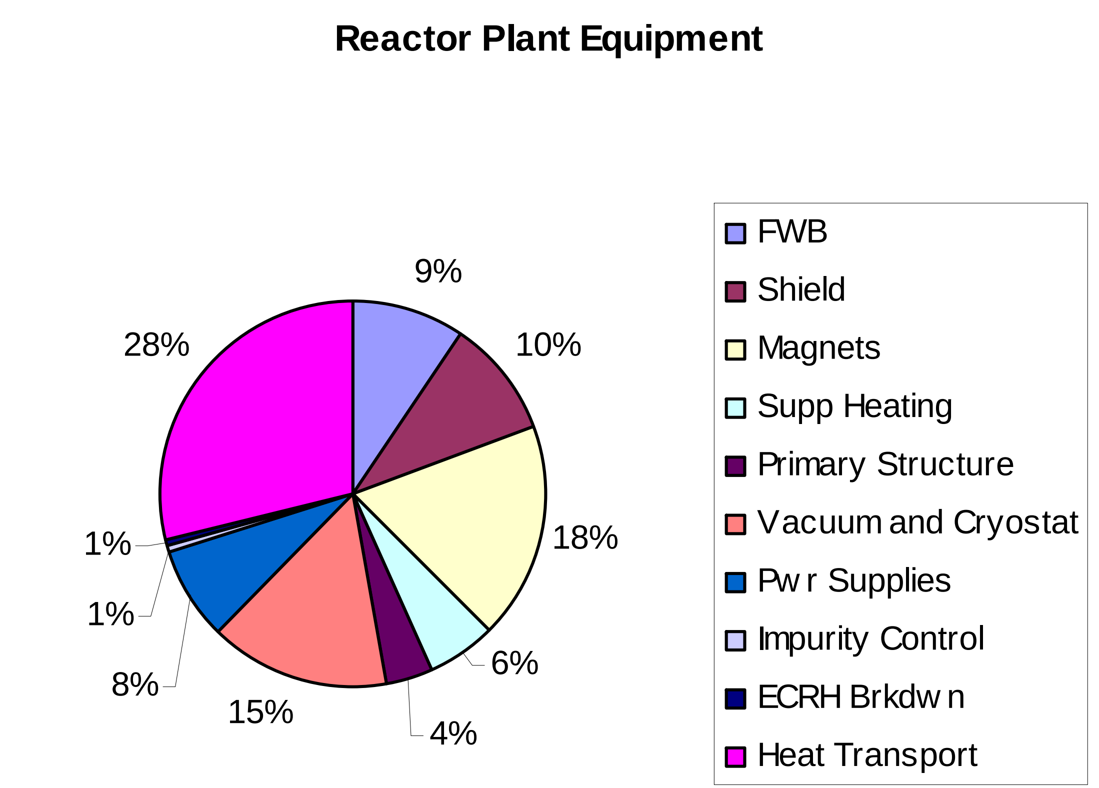
Ref: L. Waganer, "Cost of Fusion Electricity from US Studies"

- **Indirect costs reflect direct costs**
- **See next slide for RPE**
- **Structures and Site Facilities represent 19% and little can be reduced unless inherent safety is significantly improved**
- **TPE depends on heat conversion method**
- **Special Materials is dependent on design approach**
- **Others cannot be changed**

Few of these Capital Cost elements can be addressed to reduce the cost

Can the Reactor Plant Equipment Costs Be Influenced to Reduce the COE?

ARIES-AT is a typical example

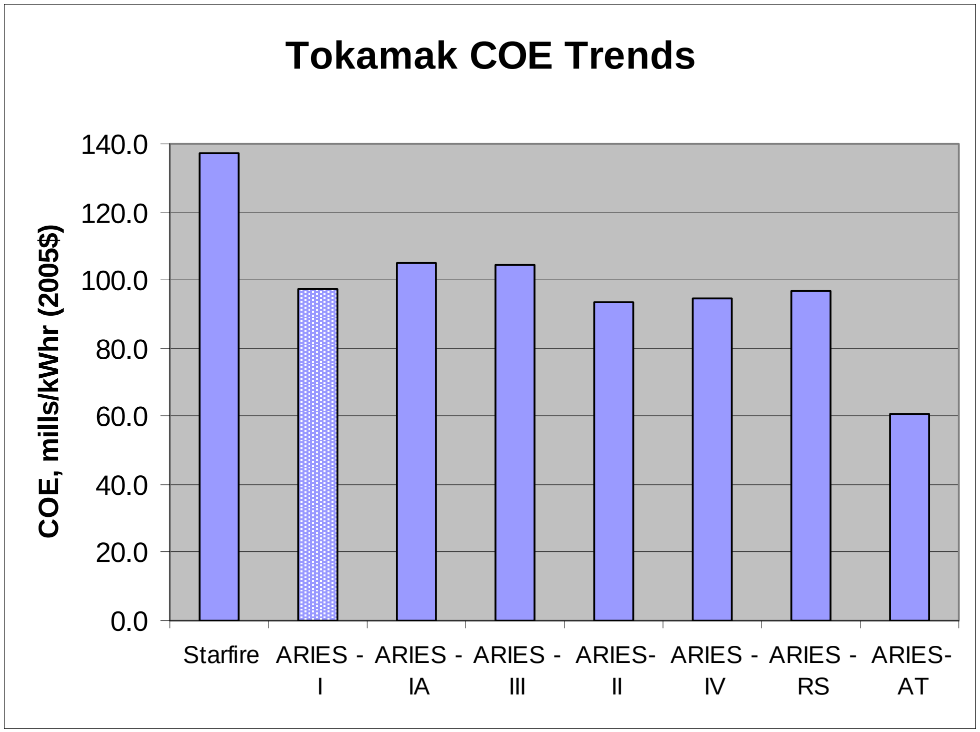


Ref: L. Waganer, "Cost of Fusion Electricity from US Studies"

- **Heat Transport is a large percentage due to high temperature operation (η)**
- **Magnets are always costly**
- **Vacuum system has expensive cryostat/vacuum vessel**
- **Life of plant shielding is tailored to protect magnets**
- **FWB is only 9%, but is periodically replaced**

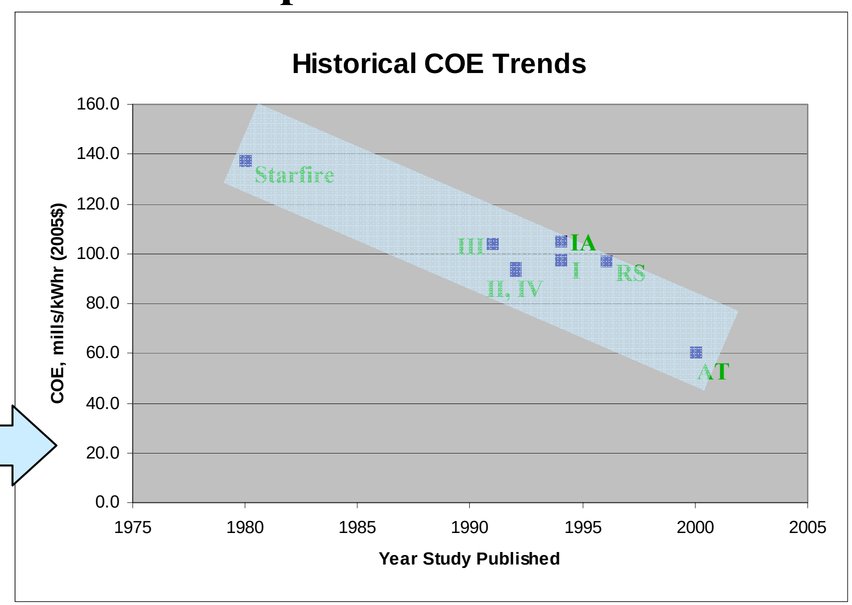
The cost of all components can be addressed, but performance improvement works in opposition to lower cost goals

Compendium of COE Values from US Tokamak Studies

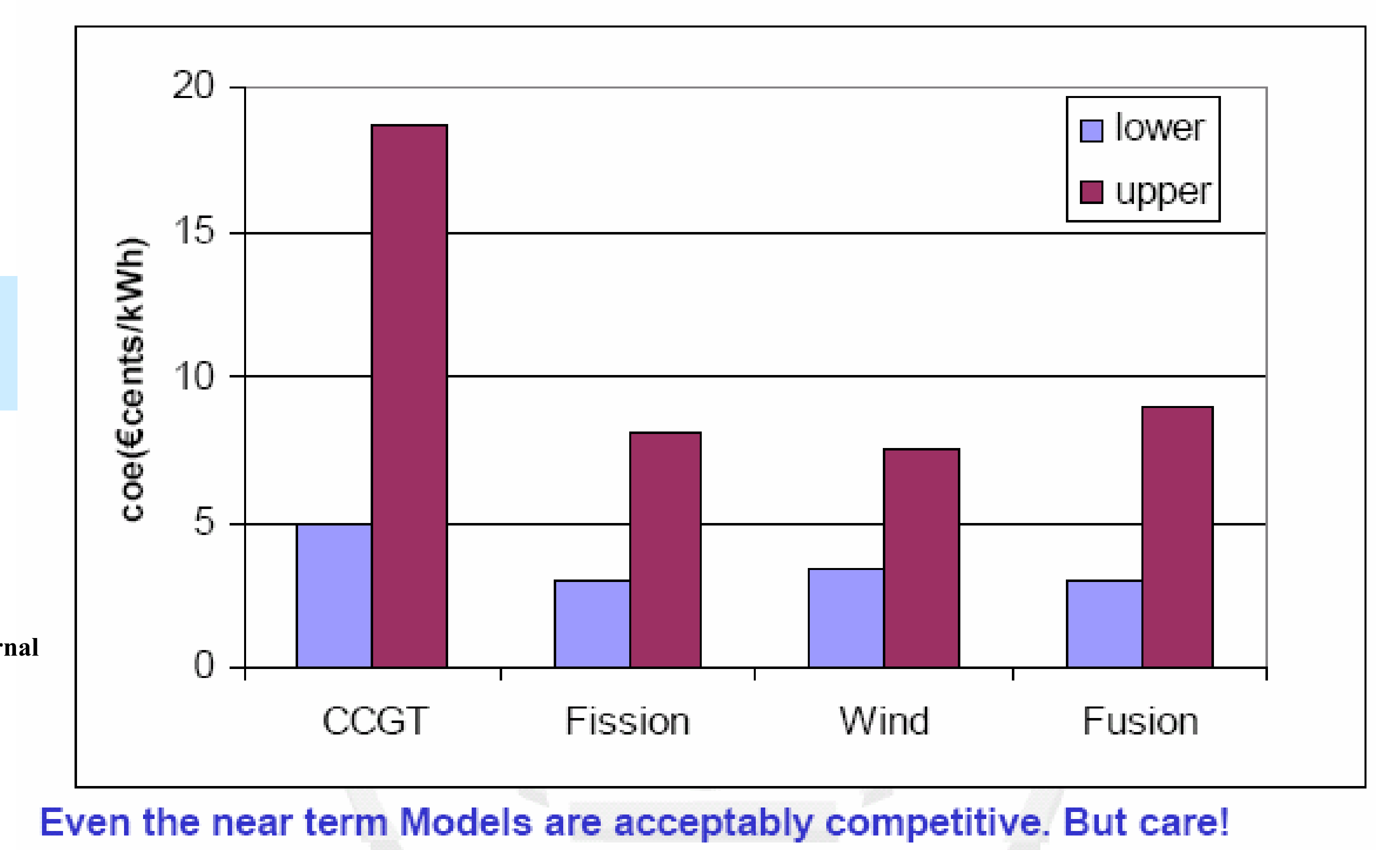


- There is a downward evolving trend, except for ARIES-RS
- Progress has been incorporated in Physics, Materials, and Engineering
- Now we need new experimental evidence to continue the cost improvements
- Should work on <u>all</u> cost factors for further improved economics

When plotted against study completion date, there is a definite trend line



UKAEA Internal Costs Comparison



Note:
1 Euro ~ $ 1.26
1 GBP ~ $ 1.84

Ref: D. Ward, "Internal Cost of Fusion Electricity form EU Studies"

Includes projected fuel price increases but no carbon tax. Wind is near-term technology, but no standby or storage costs are included.

Philosophical Differences on External Costs and Market Acceptance Criteria

- The US position is that the cost of fusion generated electricity must conform to the same rules as other sources with no external cost factors
- The cost of development of the first fusion power plants (Demo, Prototype, and first Commercial will likely be largely borne by the Government
- The capital costs for these plants will likely be borne by independent power producers
- The technical risk would predicate that the fusion COE should be 20% less than competitive electricity generation

- The EU position is that the cost of fusion generated electricity would use similar groundrules as other sources, but external costs would be included on all sources
- The cost of development and capital of the first fusion power plants (Demo, Prototype, and first Commercial will likely be largely borne by the Government
- The technical risk associated with fusion would not be a significant factor in the decision to develop fusion
- The fusion COE should only be in the ballpark to proceed with development and implementation