Summary Report of the Energy Issues Working Group

Organizer: Farrokh Najmabadi

Covenors: Jeffrey Freidberg, Wayne Meier,
Gerald Navaratil, Bill Nevins,
John Perkins, Ron Stambaugh,
Don Steiner, Ned Sauthoff

1999 Fusion Summer Study

July 12-23, 1999, Snowmass, CO

Energy Working Group Web Site: http://aries.ucsd.edu/snowmass

Energy Issues WG has Two Subgroups

- **Subgroup A**: "Long-term Visions for Fusion Power"
  - Convenors: Jeffrey Freidberg,, Bill Nevins,
    John Perkins, **Don Steiner**

- **Subgroup B:** "Range of Steps Along Development Paths, Options, Directions, Accomplishments, & Decision Criteria"
  - Convenors: Wayne Meier, Gerald Navaratil,,
    Ron Stambaugh, Ned Sauthoff

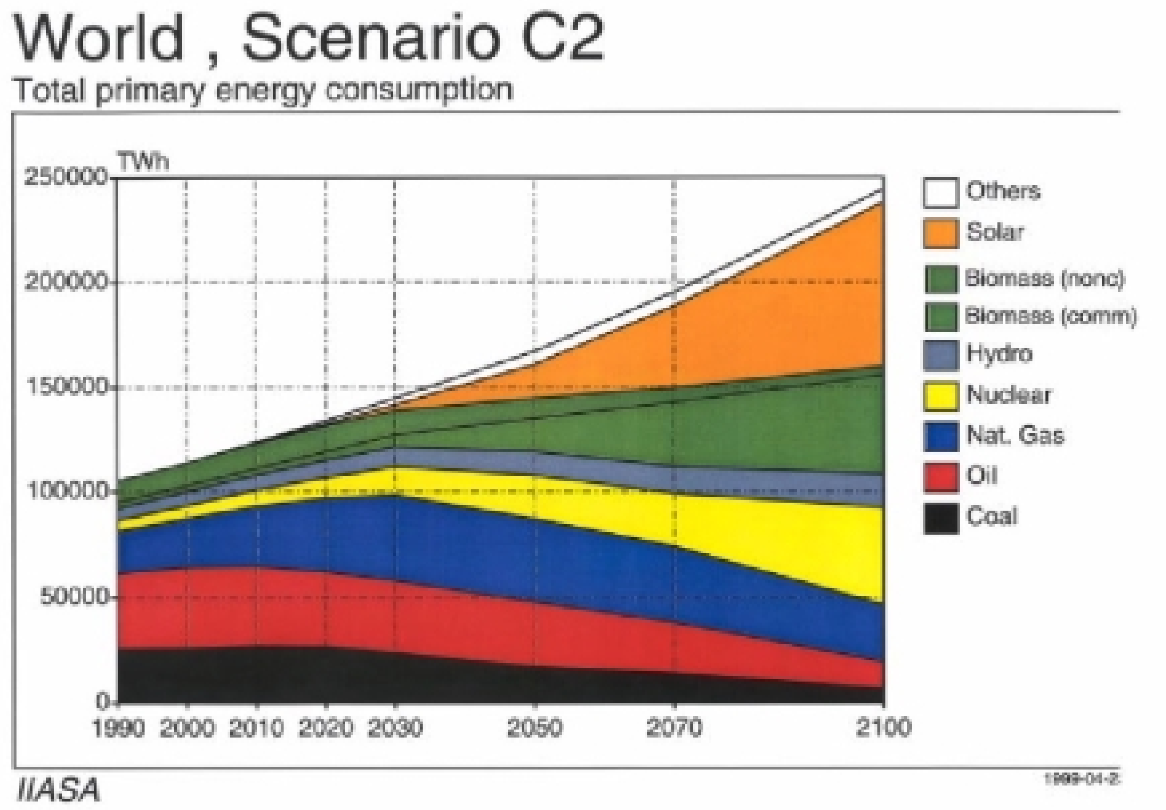
Subgroup A: "Long-term Visions for Fusion Power"

- What is the projected market for electrical energy production in the next century?
- What is Fusion's Potential for penetrating the energy market in the next century?
- Is there a potential role for advanced fusion fuels?
- What is Fusion's potential for applications other than conventional power plants?

Fusion Introduction into Energy Market

Observations:

- To meet the projected growing demand of electricity and to stabilize CO_2 concentration in atmosphere in 2050 and beyond, a large number of new power plants are required.



- This represents an opportunity for fusion energy development.

Opportunities for Fusion Development

- Our program strategy should continue to focus on scientific achievements and measured progress toward fusion energy goal.
- Moreover, we should also strive to gain broad acceptance of a plan to introduce commercial fusion energy by 2050 in order to be taken seriously by energy planners and forecasters.

Achieving the Safety and Environmental Potential of Fusion is Essential to its Competitiveness*

Metric	**Goal**
Cost of Electricity	5-6 c/kWh (1998$)
Accident dose limit	No public evacuation (<1 rem at site boundary)
Rad. Waste disposal criterion	Class C or better
Fuel cycle closed on site	Yes
Atmospheric pollutants (CO_2, SO_2, NO_X)	Negligible
Occupational dose to a worker	< 5 rem/yr
Capacity factor	> 80%
Major unscheduled shutdowns	< 0.1 per year

* FESAC Panel on program balance, metrics, and goals (draft report).

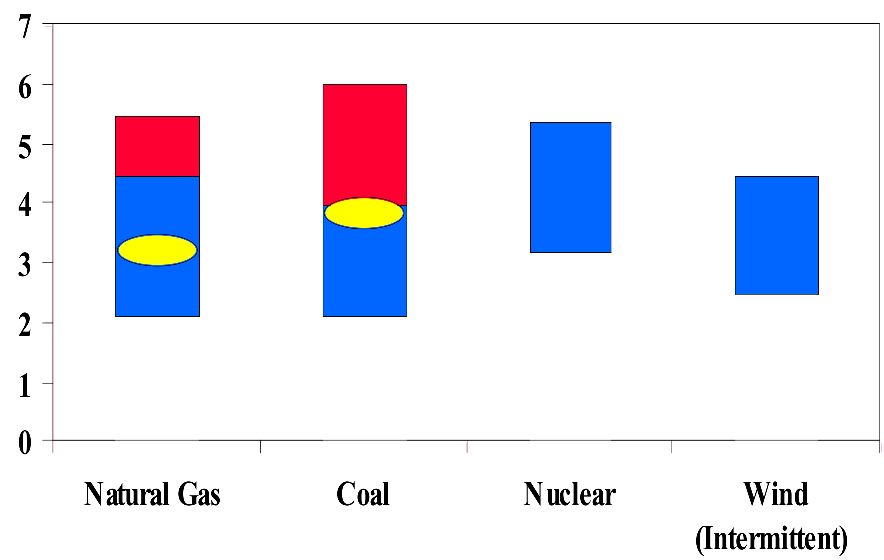
Projected COE for Future Energy Sources

Observations:

- Future energy sources (C-sequestered fossil, fission, ...) projected to be in the COE range 3-6 c/kWh.
- Design studies show that fusion can compete if its full safety, environmental, and waste potential is realized.
- Fusion development should continue to pursue physics, engineering, & technology improvements/innovations to further reduce projected COE.

Estimated range of COE for 2020

EPRI Electric Supply Roadmap (1/99)



Impact of $100/ton carbon tax.

Other Estimates from Energy Information Agency Annual Energy Outlook 1999.

Fusion Power Plant Attractiveness, Technical Risk, and Balance

Observations:

- Tokamaks could lead to an attractive power plant.
- Stellarator, ST, and IFE concepts could also lead to attractive power plants, but at this point, are behind in demonstrated performance.
- Emerging concepts may lead to improvements in power plant attractiveness but they should be evaluated mainly on the basis of physics credibility.

Opportunity/Issue:

- It is too early to narrow down to one option and a balanced program is essential.
- As concepts move through the stages of development, power plant attractiveness and development cost and time frame, should be an increasingly important metric in allocating resources.

Advanced Fuels (D-^{3}He)
Summary of Assessment, Issues, & Opportunities

Issue	**Metric**	**Goal**	**Opportunities**
Energy confinement	$n_e \tau_E T$	~10^{23} keV-s/m^3	To be addressed by Physics program
α/p -ash	τ_p^* / τ_E	≤ 3	"
Power density	βB^2	? 12 T^2	"
Synchrotron radiation	Power loss fraction	<< fusion power	Develop tools for accurate calculation
Safety & environment	Activation	Reduced waste volume	Build on ongoing engineering efforts
Operation	Radiation lifetime	Plant lifetime	"
Direct conversion	Efficiency	60%–70%	Small-scale tests
^{3}He fuel supply	Accessibility & cost	$500/g	〈 Lunar mining 〈 Breeding

Advanced Fuels (D-^{3}He)
Summary of Assessment, Issues, & Opportunities

Challenges:

- Large physics extrapolation with respect to DT fuel: (factors of ~ 50 in $n_e \tau_E T$, ~5 in βB^2, and ~2-5 in τ_p^* / τ_E)
- Large heat flux on in-vessel components and/or efficient direct conversion.
- ^{3}He fuel supply.

Potential advantages:

- Reduced waste volume.
- Plant-lifetime components

Opportunities:

- Promising physics embodiments need to be demonstrated.

Several Non-Electric Applications Have Been Proposed

- **Neutron sources for fusion-fission applications**
  (Breeding of ^{233}U, Burning of Pu and other actinides, Burning of depleted Uranium)
  - Fusion embodiment: Low Q (~1-5), CW or high duty factor, approaching power-plant technology (tokamak & ST)
  - Metrics: 1) Cost of neutrons, 2) Neutron spectrum effectiveness, 3) k_{eff}
- **Use of process heat for co-generation (e.g., hydrogen production)**
  - Fusion embodiment: Large output power plants
- **Deep-space propulsion applications**
  - Fusion embodiment: Large power output (1-8 GW), advanced fuel (D-^3He), ST, FRC, and other emerging concepts.
  - Metrics: 1) Specific impulse (exhaust velocity), 2) Specific power (kW/kg)

Summary of Assessment, Issues, & Opportunities

Item	Neutron Source	Space Propulsion
Market Penetration & Customer	〈 Nuclear power industry 〈 DOE/Waste Disposal	〈 NASA
Competition	〈 Fission 〈 Accelerators 〈 Burial	〈 One of the few options for deep-space missions.
Environment, Safety, & Licensing	〈 Applications look more like fission than fusion	〈 Safety implications not yet assessed.

Summary of Assessment, Issues, & Opportunities

Item	Neutron Source	Space Propulsion
Impact on Time-scale	〈 Could provide an intermediate mission prior to pure fusion systems	〈 NASA interest provides outside advocate for fusion development
Key Issues	〈 Must establish a market niche 〈 Impact on fusion image 〈 Impact on pure fusion development plan 〈 Technology, reliability, & availability implications	〈 Technical basis must be established
Opportunities	〈 System studies 〈 NSO program	〈 NASA/DOE cooperation

Subgroup A: "Long-term Visions for Fusion Power"

- What is the projected market for electrical energy production in the next century?

  Demand for non-polluting technologies will be enormous.

- What is Fusion's Potential for penetrating the energy market in the next century?

  It depends on pace of technical progress and demonstrating its environmental potential.

- Is there a potential role for advanced fusion fuels?

  Physics embodiments need to be demonstrated.

- What is Fusion's potential for applications other than conventional power plants?

  Several applications have been identified