2017 U.S. Magnetic Fusion Strategic Research Directions Workshops

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for the Community Workshop
Program Committee

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FESAC meeting
Gaithersburg, MD

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Community Workshop Program Committee

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Deyong Liu	University of California - Irvine	Steven Zinkle	University of Tennessee - Knoxville
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*** Co-Chairs**

Goal of Community Workshop Process

The program committee established two over-arching goals for the community work process.

1) **Provide an open forum to hear community views on strategic charge questions I2 and F2 and opportunities in charge F1, and to provide community feedback on these views.**
   - Importance of burning plasma research (charge I2)
   - Key scientific and engineering opportunities (charge F1)
   - Guidance on a strategic plan if US is/is not partner in ITER (charge F2)

2) **Identify key aspects of a long-term U.S. fusion strategic plan (both with and without the U.S as a partner in ITER) including both domestic and international research, and identify points of community consensus on the most critical key elements of that plan.**

Important Guidelines for Workshop Process

Goal: Ensure the credibility and broad support from the community for any work product resulting from the workshop(s)

Principles:

- Value input of all workshop attendees
- Value full range of ideas - be inclusive, not exclusive
- Peer review essential for scientific credibility
- Empower workshop leadership, but with appropriate checks and balances
- Engage workshop program committee in full range of decision-making

Communication: Engage with community leaders, FES leadership, and NAS panel co-chair at timely intervals for feedback on process and goals

We All Have the Same Destination But The Obvious Path to One is Not So Clear to Others

Brief Timeline of Community Workshop Process to Date

Dec 2016: NAS Task Description Released

Feb. 2017: Leadership group "commissioned" D. Maurer, J. Menard, and M. Wade to coordinate development of community workshops

Mar 2017: Program committee established

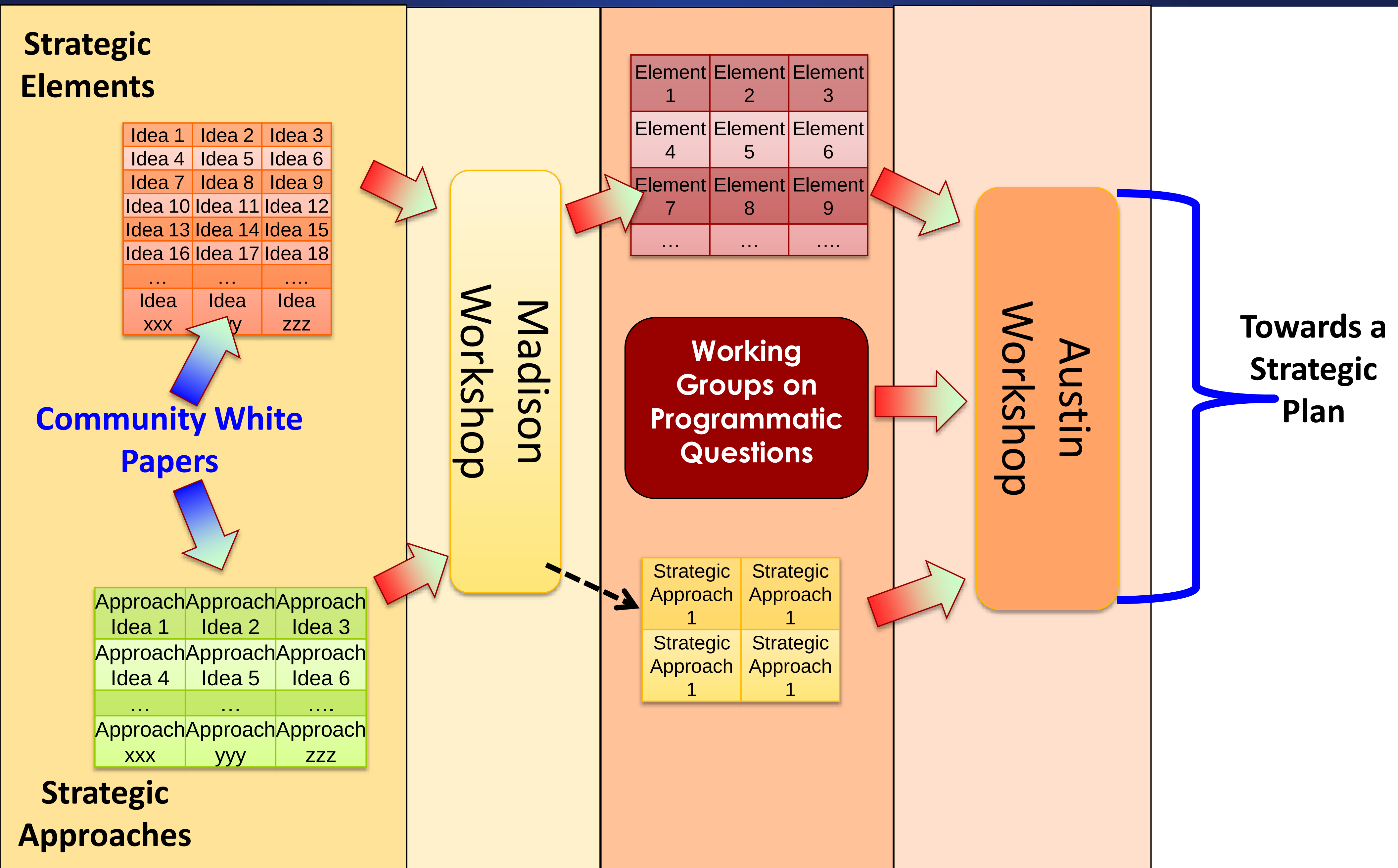
July 24-27, 2017: 1st Workshop at Madison

- focused on presentation/discussion of strategic elements

Dec 11-15, 2017: 2nd Workshop at Austin

- broader set of issues (attractiveness, impact of ITER, approaches)

Community Process in Visual From



Madison & Austin Workshop Structure

- **Morning Sessions devoted to plenary talks**
  - Presentations organized along broad topical lines (Madison) or by working groups (Austin)
- **Afternoon Sessions devoted to breakout discussion of morning talks**
  - Discussion groups
    - Led by PC members (Madison) and community members (Austin)
    - Remainder of each group determined by "lottery" with adjustments made to ensure institutional and topical balance
  - Each discussion were provided with guidelines and questions but were empowered to guide discussions at their own choosing
    - Encouraged (but not forced) to reach consensus on group perspectives
- **Each breakout discussion group presented their "findings" in plenary session on Friday morning**
- **Co-chairs produced summary of summaries trying to find consensus points in the breakout summaries**

High Level Summary (1)

- Agreement that there are many exciting opportunities for US leadership

- Critical need for a strategic plan/roadmap for fusion research going forward

- The community should lead a on-going strategic planning process and set scientific priorities; This will ensure strong community support for the generated strategic plan

Madison

Slides taken directly from D. Maurer's Summary Talk of Madison Meeting

High Level Summary (2)

- The US program has strengths but it is not healthy overall (universities and technology). The trajectory is in the wrong direction in general
- Discussion centered around being a science program vs. energy, but no clear consensus, good issue to discuss going forward

Madison

Slides taken directly from D. Maurer's Summary Talk of Madison Meeting

Summary of Strategic Elements (1)

- Burning plasma is still an essential step for our field

- The program should have an element that would focus on developing HTS magnets for fusion applications; Potential game changer.

- Configuration research: A wide variety of comments, more discussion needed going forward

- General interest in and support for stellarator component to US program; Potentially transformative

Slides taken directly from D. Maurer's Summary Talk of Madison Meeting

Madison

Summary of Strategic Elements (2)

- Theory/computation important component; Need to balance analytic theory, and computing at various scales (exa/capacity) for effectiveness and validation purposes

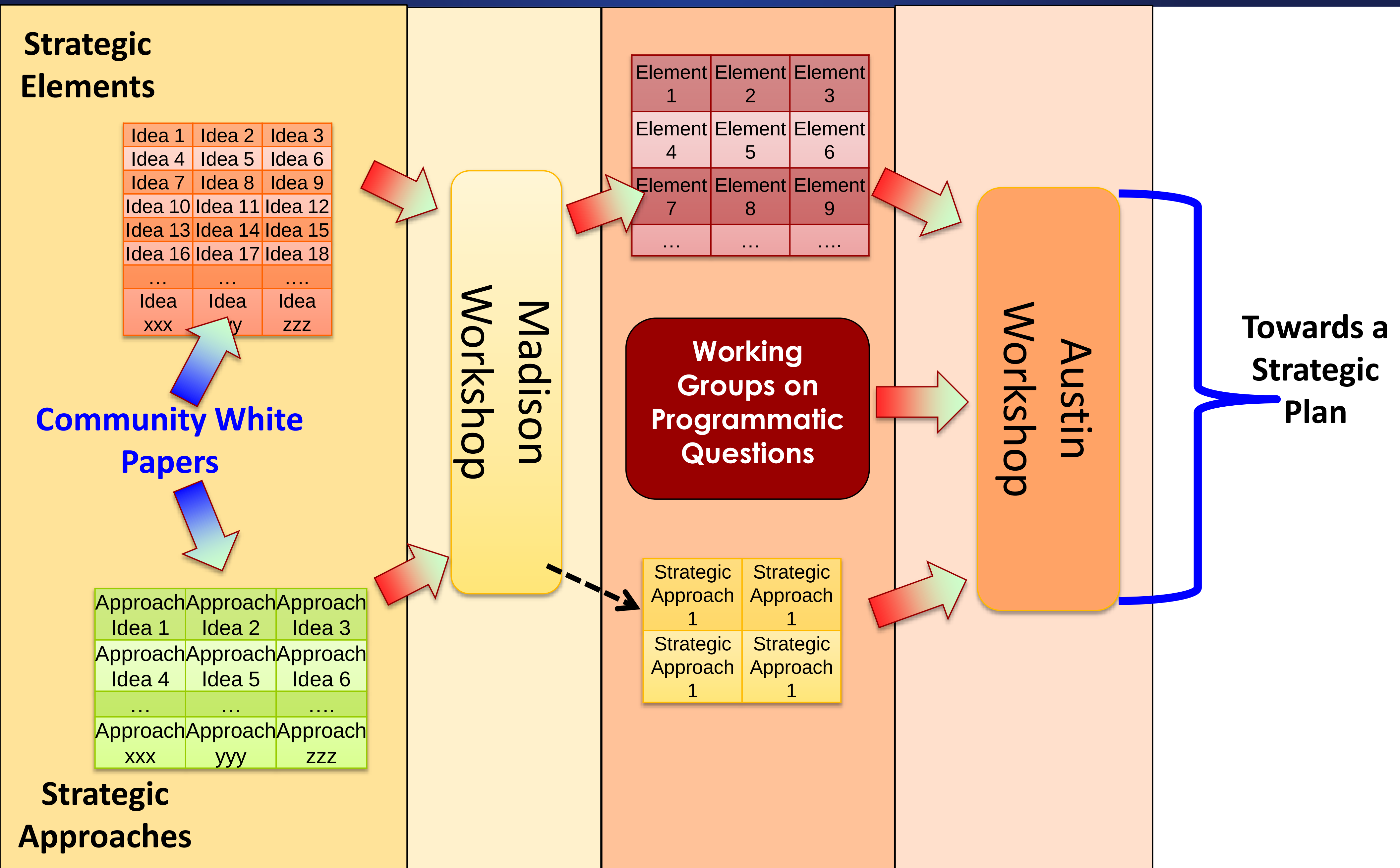
- PMI/divertor problems very important, compelling options need to be evaluated

- FNS/TB/blankets are a critical element on the path for fusion energy development; Concerns about timeline and number of steps in path to develop a FNSF

Madison

Slides taken directly from D. Maurer's Summary Talk of Madison Meeting

Community Process in Visual From



Austin Workshop touched on all levels of strategic planning due to urgency, goal of community engagement

- WG1 – Principles, Values, Metrics, and Criteria
- WG3 – Market Attractiveness Working Group

- WG2 – Impact of Access to ITER Physics and Technology Development
- SA1 – Use Present Physics and Technology Basis for DEMO
- SA2 – Deliver Key Technical Achievements Then proceed to DEMO
- SA3 – Innovate Tokamaks & Stellarators First, Then Proceed to DEMO
- SA4 – Develop and Advance Alternative Concepts for DEMO

- WG4 – Review/Characterize Key Strategic Elements from Madison
- WG5 – Fusion Science / Plasma Physics / Materials Science Integration

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- WG6 – Future Planning Activities – Moving forward from Austin

Ongoing development/iteration of strategic plan

Pre-Austin

Population of Pre-Austin Working Groups

- **Leadership team for each group established by program committee**
  - Generally consisted of advocates and expert in other areas
- **Working groups open to everyone**
  - Subscribed through workshop website
  - All correspondence through Google email group

	Working Group Name	# Members
WG-1	Principles, Metrics, and Criteria for Assessing Strategic Plan	29
WG-2	Impact of Access to ITER	35
WG-3	Attributes for Market Attractiveness	41
WG-4	Review and characterize key strategic element from Madison Workshop	26
WG-5	Fusion Science/Plasma Physics/Materials Science Program Integration	30
WG-6	Future planning activities - moving forward from Austin	15
SA-1	Use present physics and technology basis for DEMO	21
SA-2	Deliver key technical achievements then DEMO	23
SA-3	Innovate mainline physics and technology then DEMO	38
SA-4	Develop and advance alternative concepts for DEMO	16

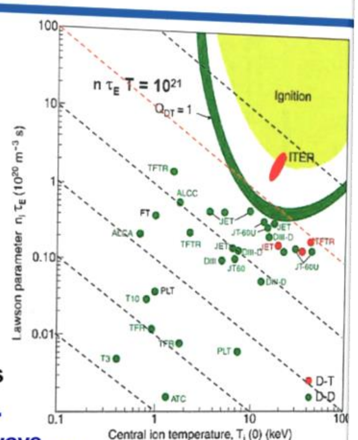
WG-1: Principles, Values, Metrics, and Criteria

"Develop a comprehensive set of principles, metrics, and criteria that are important in developing an exciting and credible strategic plan for delivering fusion energy in the next several decades."

- **WG developed list of:**
  - Essential criteria for a MFE fusion power plant
  - Principles and values to evaluate strategic approaches
  - Metrics and criteria to evaluate strategic objectives

"Hard" Metrics for Fusion Plasma Performance

1. Fusion power output
2. Q = Fusion power / Power losses
   a. Lawson criterion for nτ
   b. Optimal Lawson temperature range T
3. Fusion power / Recirculating power
   a. Heating, current drive, cooling, fuel cycle, …
4. Operational limits
   a. MHD limits: pressure and current
   b. xMHD limits: density, temperature, …
   c. Tokamak limits: ELMs, VDEs, disruptions, ….
5. Ability to predict & avoid/detect & mitigate transients
   a. Avoid/mitigate disruptions, thermal collapses, …
   b. Limit damage/erosion due to heat, forces, runaways, …
6. Heat flux on first wall and divertor, radiated power fraction
7. Neutron flux on first wall
8. Tritium burnup fraction
9. Availability, pulse length, and load-following capability



+ a comprehensive list of potential "soft" metrics (less quantitative, more quantitative)

WG-2: Impact of Access to ITER

"Develop a list of the technical impacts (including scientific, technological, operational, …) and programmatic effects (e.g., reputation, international cooperation) of the U.S. losing access to ITER under two scenarios: a) the U.S. withdrawing from ITER and ITER continuing; and b) loss of ITER in worldwide program."

- **WG developed list of:**
  - Technical deliverables/benefits of U.S. access to ITER

Technical deliverables expected from ITER or any burning plasma experiment

Sustained/controlled burning plasma regime with significant plasma gain (P_{fus}/P_{input}) over long durations determined by core plasma time-constants

Fast alpha particle confinement, instabilities, diffusion, redistribution and losses

Particle behavior in plasma chamber, fueling, exhaust, impurities, and particle control in the core plasma/burn control

PMI/PFC interaction in burning plasmas, ELMs and disruptions (*Be FW ITER specific*)

H/CD systems integration with plasma, performance and reliability at high power

Advanced operating modes, steady state, burning plasma and bootstrap fraction

Impact of alpha heating and particles on energy and particle transport, extended-ideal MHD

Resistive MHD, neoclassical tearing modes

Divertor operation in detached regime, control of this operation in conjunction with core plasma

The burning plasma demonstration is fundamental to moving to fusion energy!

Technical benefits of ITER (several technical aspects represent major progress toward fusion energy, but can require significant further advances for next steps and DEMO)

Super-conducting TF/CS/PF and error field correction coils (Nb_3Sn & NbTi)

Large scale vacuum pumping system

Tritium processing plant, and associated systems (significant breeding loop for DEMO)

Cryoplant and cryodistribution system

Pellet fueling systems

Plasma facing components (material changes going to DEMO)

Remote handling (port-based articulated arm, not long term relevant)

Attempting in-vessel coils (in-vessel refers to behind blanket and shield in next steps)

Plasma control systems

Heating and current drive systems (DEMO requires higher efficiencies)

Diagnostics (becoming more difficult as go to DEMO)

TBMs (higher neutron exposures in next steps)

Safety and licensing activities

Hot cell, radwaste treatment and storage (significant leap required for next steps)

Pre-Austin

WG-3: Attributes for Market Attractiveness

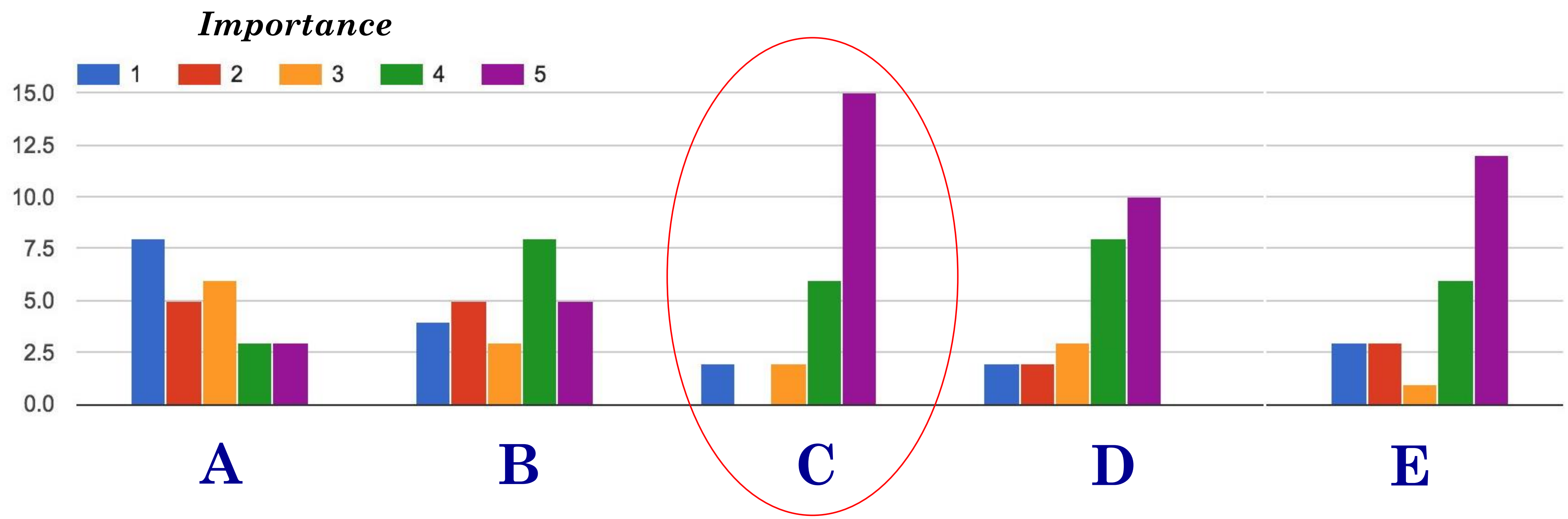
"Develop a list of attributes that utilities, energy institutes, environmental agencies, and private investors consider when assessing the potential for fusion for future energy markets"

- **A survey focused primarily on U.S. market was developed and distributed to members of those communities**
- **To accomplish this, WG *asked*** →
- **Ryan Umstattd, ARPA-E Deputy Director for Commercialization (Acting), provided additional input in a talk entitled: "*Observations on Fusion Power Market Attractiveness*"**

Utility managers
Government representatives
Energy technology firms
VC & investment groups
Energy policy and consulting
Privately funded fusion ventures
25 total responses

Pre-Austin

Example from Survey: Achievements needed to commit private funds?



(A) A plausible reactor concept supported only by scientific analysis, numerical simulations, and preliminary experimental data

(B) Demonstration of fuel conditions (i.e., temperature, density, duration) needed for energy breakeven

(C) Demonstration of net energy gain (fusion energy exceeds "wall plug" energy)

(D) Demonstration power plant with nearly continuous thermal energy output

(E) Maturation of at least one fusion approach that offers the timely potential for power production at lower costs than a comparable-capacity nuclear-fission power plant

Pre-Austin

WG-4 Provided Potential Mapping of Strategic Elements to the Various Strategic Approaches

Main contributions, updated based on the plans presented at this meeting.

SA-1: Use present physics and technology basis for DEMO
SA-2: Deliver key technical achievements then DEMO
SA-3: Innovate mainline physics and technology then DEMO
SA-4: Develop and advance alternative concepts for DEMO

Essential or high impact

Option or moderate impact

	Burning Plasma	HTS	Configu-rations	Stellar-ator	Theory	PMI program	FNS program
SA-1	[green]	[orange]			[green]	[green]	[green]
SA-2	[green]	[green]		[orange]	[green]	[green]	[green]
SA-3	[green]	[green]		[green]	[green]	[green]	[green]
SA-4	[green]	[orange]	[green]	[green]	[green]	[green]	[green]

Each Strategic Approach also needs other elements
Many are in the current fusion program, others new or needing enhancement.

Pre-Austin

WG-5: Fusion Science/Plasma Physics/Materials Science Unification/Program Integration

"Outline a proposal to unify basic and fusion plasma and materials science into a "Grand Challenge" program approach for the US"

Challenges Identified:

- Uniting and fully exploiting capabilities of MFE community
- Better integration with neighboring communities that can contribute to fusion research
- Need to grow support for fusion research in the larger scientific community

Recommendations Made:

- Change the way we organize opportunities for research in order to unite us and more fully utilize all capabilities
- Partner with other agencies, in particular DOE BES, to integrate materials science research into the MFE program
- Bring collaborators from other science areas to MFE
- Enhance/improve outreach to other communities

Pre-Austin

WG-6: Future planning activities – moving forward from Austin

"Define the purpose, approaches and governance for follow-on activities, especially long-term, community-led strategic planning"

Synthesis: The View From WG-6 – Following Past Successful Models – We Seek

- Recognition of a broad, common interest from community and DOE for development and update of strategic plans
  - Could be triggered by a charge to FESAC – With enough time to work!!!
- Concerted community activities – working groups, etc.
  - Culminating in a broad-based multi-week workshop
  - Sponsored by APS-DPP, Universities and Labs
  - Compliant with Advisory Committee Act (FACA) – So it can work outside those restrictions
  - Product is a report with significant technical detail and community buy-in
- DOE responds with charge for FESAC (if one hasn't already been issued to drive process)
  - FESAC Panel takes community report (and other input) and makes its findings and recommendations
  - Adopted and forwarded by full FESAC to DOE/SC
- Interval TBD, but (for example) HEP has concluded that a 5 year cycle is tractable and desirable.

Pre-Austin

Strategic Plan vs. Strategic Approach

Strategic Plan: Comprehensive framework that defines

- The mission – what is to be accomplished
- A vision for how the mission will be accomplished with acceptable risk
- Principles for making decisions along the way
- A roadmap that outlines how the plan will unfold

To mitigate risk to the extent possible, strategic plans typically blend various approaches (see below) to achieving the mission, leading to multiple potential branches in the roadmap. The pathway through the roadmap is determined by key decision points that define initiation/continuation/termination points for the various branches.

Strategic Approach: One of many potential singular paths in which the mission of a strategic plan could be accomplished. Approaches are typically differentiated through assumptions with regard to the current situation, risk uncertainties, risk tolerance, time frame, and competitor positioning.

Example

Situation, Mission, & Desired Outcomes

Current Situation:

- April 2
- 5000 troops in Kansas

Mission:

- Fortify defense regiments in Sacramento by October 30

Objectives:

- Safety of all troops
- 1000 troops in Sacramento by July 31
- All 5000 troops in Sacramento by September 30

Strategic Plan Development

What is most risk-acceptable plan to ensure 1000 troops by July 31 and 5000 by September 30???

- 1 team of 5000 on one route
- Teams of 3000/2000 on separate routes
- Teams of 1000 on five routes
- None of the above

To answer the question above, need to establish:

- Principles for decision making
  - What will be valued??
- Risk/reward/other considerations for specific approaches of how to get those troops there on time

Strategic Approach Considerations:

What are the benefits of the approach?

What are the known challenges/risks?

What uncertainties introduce risk to mission?

What's the probability of success?

What is the expected time frame for completion?

What are the required resources (food, water, ammunition, horses, wagons, …)?

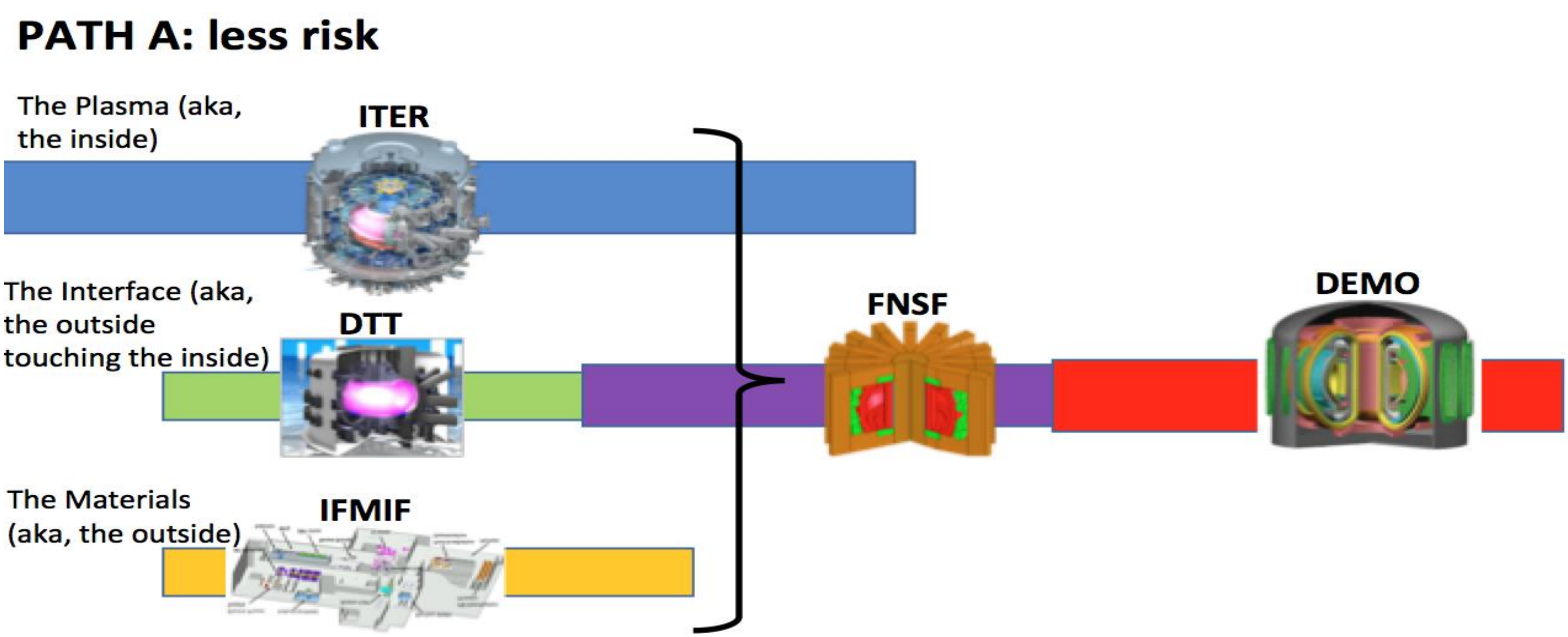
What decision points do we anticipate along the way and metrics for making them?

Once these questions are answered, can develop the plan that offers the best "risk/reward" by ***blending*** the various approaches appropriately

SA-1: Use Present Physics and Technology Basis for DEMO

"Proceed now towards DEMO building on the present physics and technology basis."*

- **Assume traditional U.S. definition for DEMO and developed three pathways**



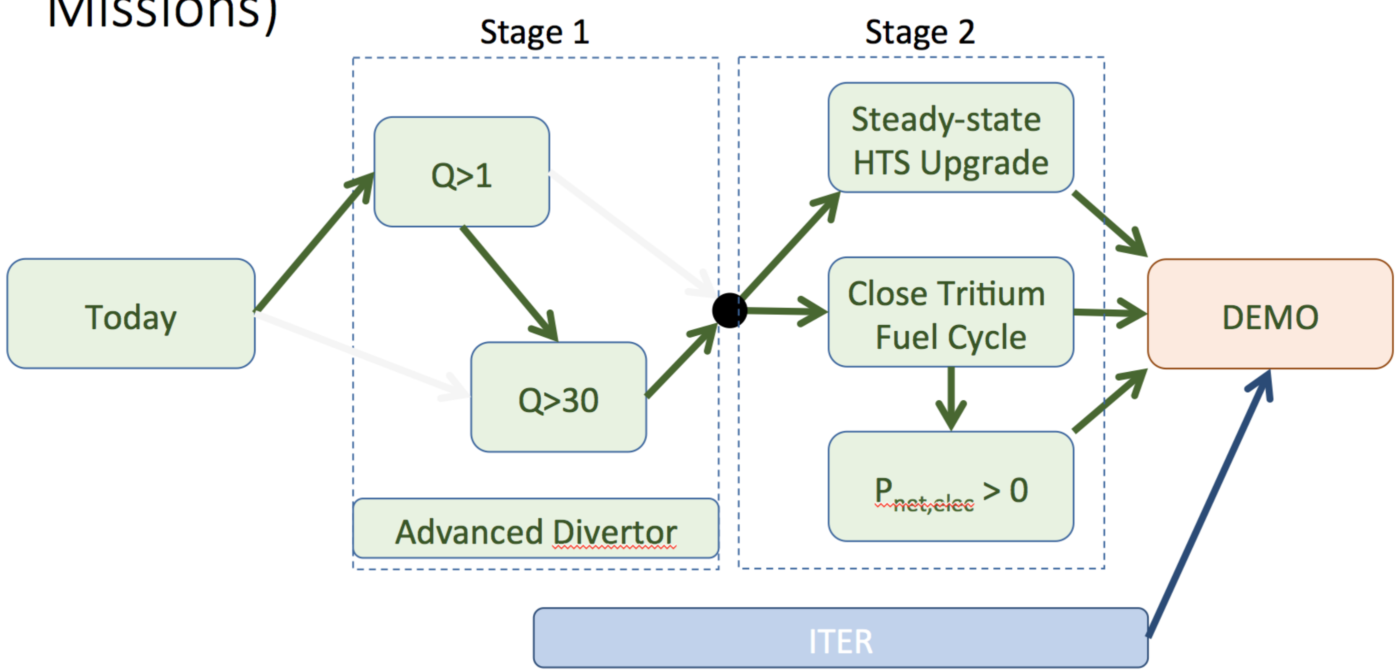
SA-2: Deliver Key Technical Achievements (e.g., Q_{plasma} > 1, P_{elec} > 0), then DEMO

"Deliver key technical achievements (e.g., Qplasma > 1, Pelec > 0) as soon as possible, then optimize concept and develop technology for DEMO*."

Proposed pathway with successive achievement of key technical objectives:

- **Q_{plasma} > 1**
- **Q_{plasma} > 30**
- **Close the Tritium Fuel Cycle**
- **$P_{net\ electric}$ > 0**

Technical Achievement Roadmap (Combined Q Missions)



SA-3: Innovate mainline physics and technology, then DEMO

"Extend the present basis by assessing potential innovations in mainline configurations (e.g. pursue advanced/compact/spherical tokamaks, quasi-symmetric stellarators, etc) and/or technology (e.g. pursue improved magnets, blankets, computing, etc), then proceed to DEMO ."*

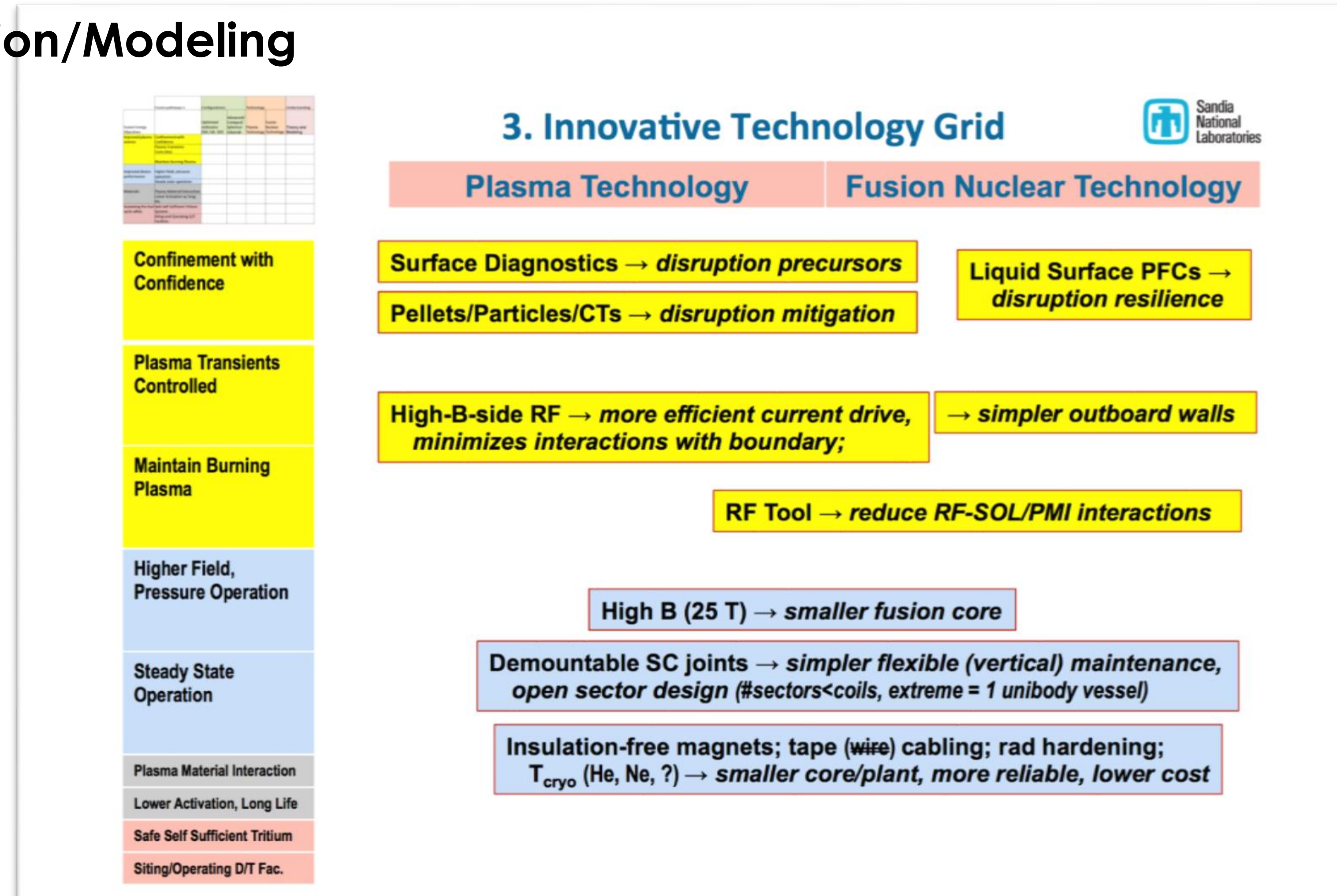
- **Decided it was impossible to achieve the entire charge in time available**
- **Limited goals to something achievable**
  - Skip risk assessment for now
  - Gap analysis -> Use gaps defined by the Greenwald Report
  - Define innovations for each gap
  - Define closing the gaps as the goals
  - Group the mainline approaches and innovations into 3 pathways to achieve the goals

Pre-Austin

SA-3 Efforts Focused on Developing Pathways in Three Separate Areas

Areas:

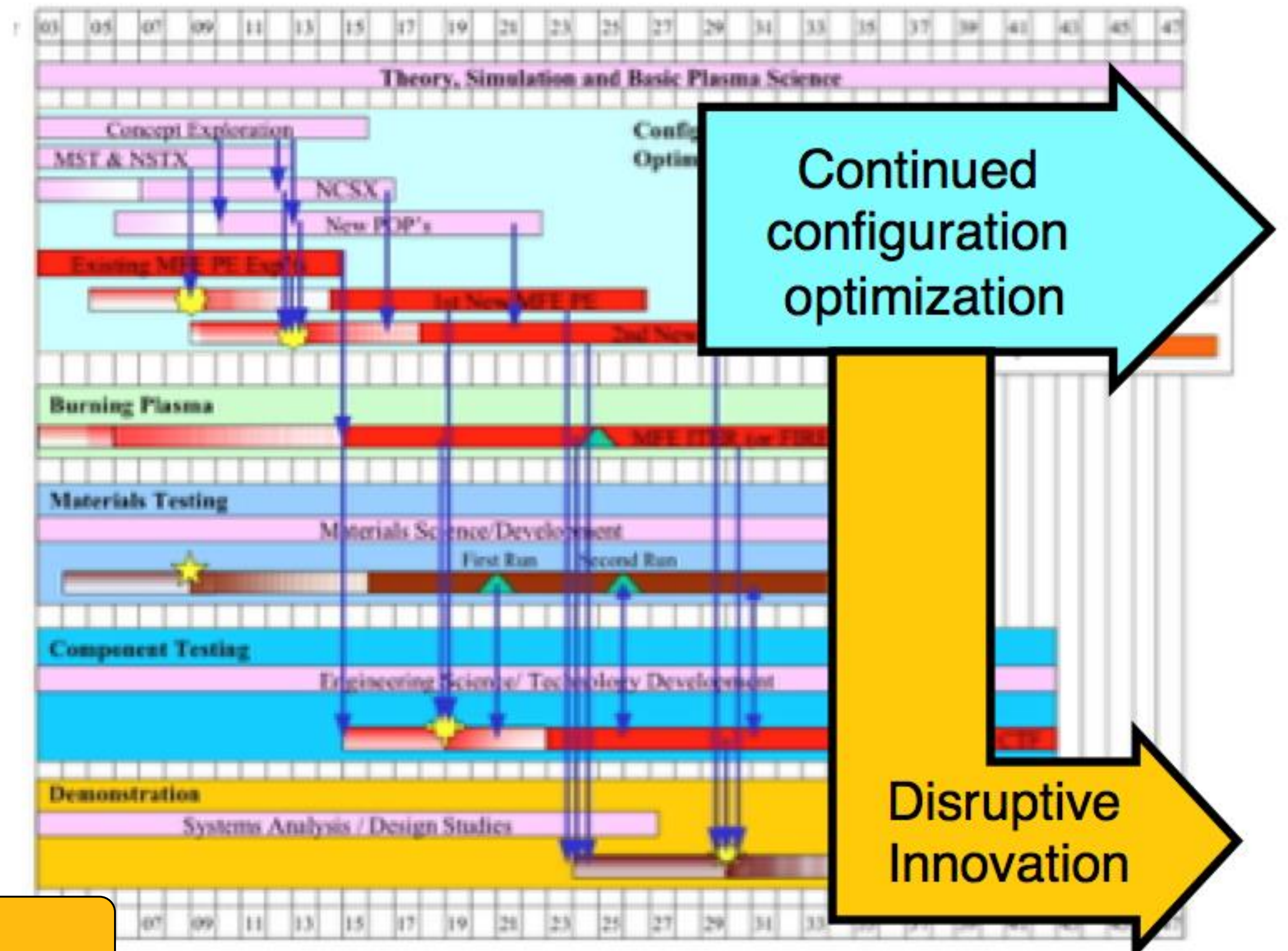
- Configuration Pathways
- Technology Advancements
- Theory/Simulation/Modeling



SA-4: Develop and Advance Alternative Concepts for DEMO

"Develop several alternate concepts to sufficient states of maturity/performance to enable objective comparisons between alternates and mainline configurations, then down-select and proceed to DEMO"*

- **Developed potential pathways that enabled configuration optimization alongside mainline program to enable disruptive innovation**



Pre-Austin

Selected Points of Consensus from the Austin Workshop Summary Presentation (1)

Working Group	Consensus Statements
WG-2 (Impact of ITER)	• Burning plasma mission is an essential step on the path to fusion energy • Operational and experimental experience (including failures) is very valuable. “Reading the papers” is insufficient to understand burning plasmas & technology.
WG-3 (Attractiveness)	• Current R&D program should be influenced but not determined by current market trends, noting long development time for fusion • Future R&D program should be flexible enough to respond to emerging market trends, including future power plants with ~0.2-1.5 GWe
WG-4 (Strategic Elements)	• HTS magnet development should proceed • Increase emphasis on advanced divertor and PFC concepts • Increase emphasis on steady-state high-performance regimes
WG-6 (Moving Forward from Austin)	• Community planning process should continue beyond the NAS study • Another community workshop should occur, if feasible, to synthesize the WG outputs and arrive at consensus on a prioritized list of Sas • Process is producing valuable information for the program moving forward and is producing valuable guidance for FES

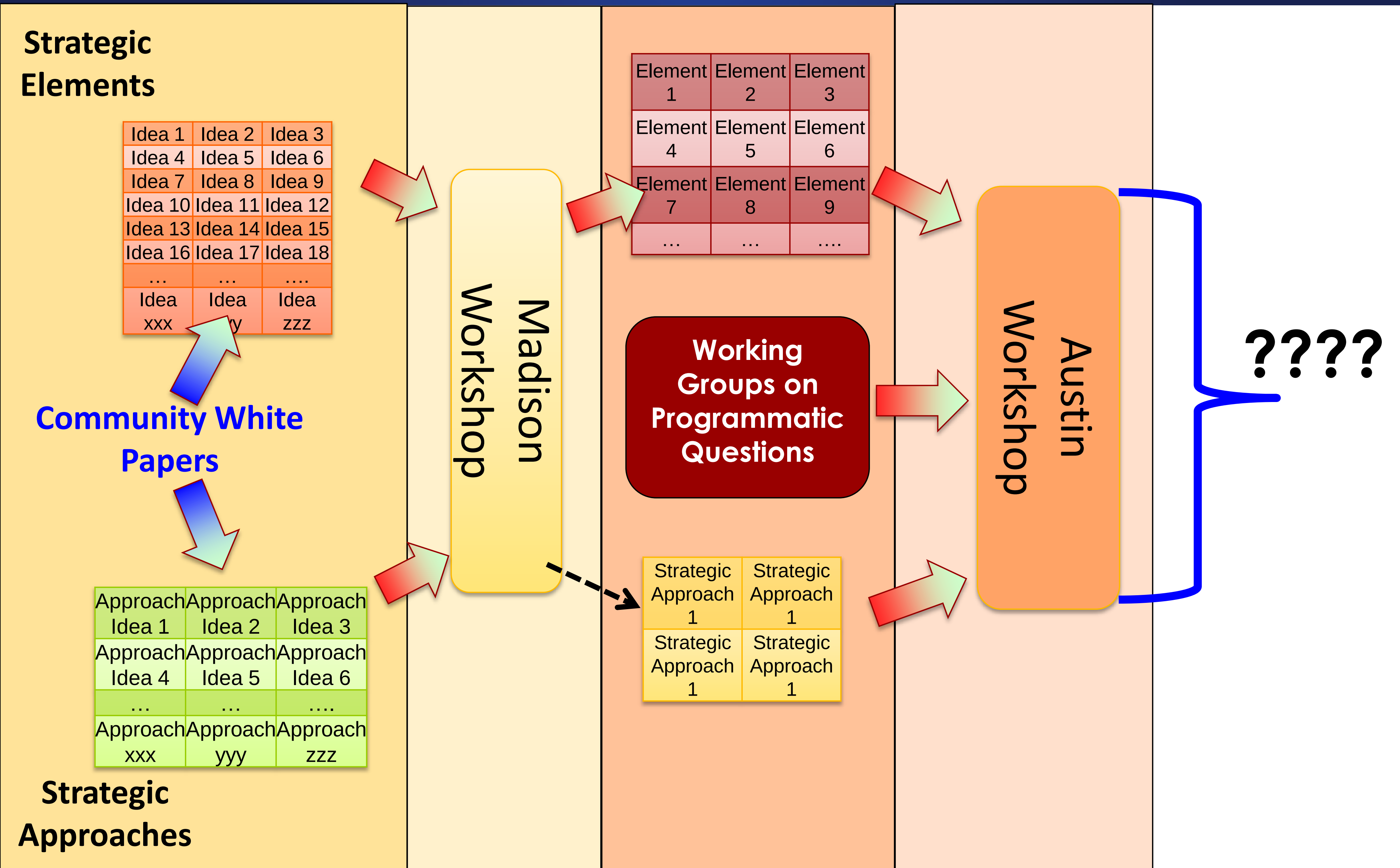
Selected Points of Consensus from the Austin Workshop Summary Presentation (2)

Working Group	Consensus Statements
SA-1 (Proceed now to DEMO)	• Path that includes ITER, IFMIF+FNSF+DTT is most reasonable path of those presented by this SA • However, the US should pursue a more innovative research path than any of proposed path(s) outlined in this SA • Materials development/qualification should be important element of program

SA-2 (Deliver Key Achievements, then DEMO)	• Divided opinions on "Q of a few" mission.
	  • PRO: could re-invigorate US fusion development
	  • CON: May be too close to previous JET/TFTR performance to generate new science or attract funding

SA-3 (Innovate, then DEMO)	• Recommend complementary approach of utilizing the delineated innovations as a "toolbox" for all the SAs to consider or use
SA-4 (Develop Alternate Concepts for DEMO)	• The US should have a 'Skunkworks'-like part of the program for range of reasons • Program should carry out merit-based, scientific and technological review of magnetic configurations including ongoing evaluation of progress and the potential for transformative breakthroughs

Community Process in Visual From



Path Forward for Community Process (1)

- **PC has commissioned white papers on 9 strategic elements emerging from Madison/Austin workshops:**
  - Burning plasma
  - Developing HTS magnets for fusion applications
  - Configuration research
  - Stellarators
  - Theory/computation
  - Plasma-material interactions and divertor
  - Fusion nuclear materials
  - Tritium fuel cycle
  - Sustained high performance tokamaks
- **White papers will have common format including benefits, current status, programmatic context, 15-year U.S. research agenda, directions beyond the 15-year horizon, critics' objections, and <u>references</u>**
- **Goal is to provide these to NAS panel prior to Feb. 26-28 mtg in San Diego**

Path Forward for Community Process (2)

- **In process of requesting a white paper from each of the pre-Austin strategic approach working group covering:**
  - Benefits of this Approach
  - Essential/important Strategic Elements
  - Impact of access to ITER
  - International Context
  - Decision Points

- **Targeting ~ April 15 for sending completed white papers to the NAS panel**

- **Third Workshop??? PC will be discussing in its next conference call**
  - Good reasons for not having it; good reasons for having it

QUESTIONS?

All information is stored on the community workshop website http://usmfrsd.org

WG1 – Principles, Values, Metrics, and Criteria

- Thorough and comprehensive work by this WG - thank you!
- Principles and Values - Consensus / multi-DG comments
  - Too many principles / values – examples for consolidation include:
    - ‘Focus on Solving Societal Problem’ should not be a principle/value.
    - Combine ‘Scientific Basis’ and ‘Quest for Knowledge’ into one principle/value
    - Some proposals to combine ‘US Leadership’ and ‘International Context’ to balance quest for leadership with reality that US cannot lead in every area
  - Need to update post-Austin accounting for comments at Austin
- Criteria – not much discussion of these
- Metrics - Many groups felt the list of metrics was too exhaustive, overly constraining. Several: suggested that strategic approaches develop metrics for their particular pathways, suggested that cost/size should be included as a metric.

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

WG3 – Market Attractiveness Working Group

- Consensus that market attractiveness survey was interesting and illuminating of current thinking. Regular updating of market trends should be done in future

- Consensus that current R&D program should be influenced but not determined by current market trends, noting the relatively long development time for fusion.

- Consensus that future R&D program should be flexible enough to respond to emerging market trends, including future power plants with ~0.2-1.5 GWe

- Many groups expressed view that mission of the U.S. program should be to develop innovative, compact solutions for future fusion power plants. This is consistent with noted U.S. market trend P_{elec} ~0.2-0.5 GWe from WG-3 survey.

- Some groups noted significant market opportunities may exist internationally for fusion, and future R&D program should remain cognizant of these

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

WG2 – Impact of Access to ITER

Consensus points:

- Burning plasma mission is an essential step on the path to fusion energy - there is broad community support for burning plasma physics.
- Operational and experimental experience (including failures) is very valuable. "Reading the papers" is insufficient to understand burning plasmas & technology.

Important Multiple-Discussion-Group comments:

- Remaining in ITER (and provided ITER achieves its projected performance) would provide critical burning plasma science needed to progress to fusion energy.
- WG-2 had good list of physics/technical benefits of ITER. Could increase emphasis on rho-star scaling of transport, disruption PAM, runaways, T handling
- Leaving ITER could threaten future US international collaborations

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

SA1 – Use Present Physics & Technology Basis for DEMO

- General consensus that of pathways presented, path A is most reasonable

  REMINDER: Path A = "Low Risk" = *ITER → IFMIF+FNSF+DTT (some in parallel) → DEMO*

  Path AB = "Intermediate Risk" = *ITER → FNSF+ → DEMO*

  Path B = "High Risk" = *No ITER , no Q=5 device → DEMO*

- But, also a general consensus that the US should pursue a more innovative research path than proposed path(s) outlined in this SA

- General agreement that materials development/qualification should be important element of program

- Lack of consensus on placement of "FNSF mission" in plan – some before DEMO, some after a pilot plant

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

SA2 – Deliver Key Technical Achievements, Then DEMO

- Divided opinions on "Q of a few" mission.
  - PRO: could re-invigorate US fusion development, especially if part of a more ambitious long-term plan, and if US is not a participant in ITER
  - CON: May be too close to previous JET/TFTR performance to generate new science or attract funding, arguably duplicative of ITER mission
- Majority of DGs expressed concern over availability of divertor solution for all the facilities/steps advocated
- Several DGs stated concern over overly-optimistic cost and schedule estimates
- Several DGs commented in favor of missions that extend beyond ITER including: high-gain (Q~30), closing the T fuel cycle, and net electric even if for shorter durations (TBD) and modest neutron wall loading (few 10s of dpa)

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

SA3 – Innovate Tokamaks & Stellarators, Then to DEMO

- No detailed strategic approaches / roadmaps yet laid out for the 3 configurations (AT,ST,QSS) due to lack of time and information.
- Several groups advocate future road-mapping for each of the 3 configurations to identify common/shared needs for innovation
- Several groups recommend complementary approach of utilizing the innovations outlined in SA-3 as a “toolbox” for all the SAs to consider or use – again to identify linkages / leveraging across configurations – potentially improving all of them
- Wide agreement fundamental theory and modeling underpin all configurations in SA-3 and other SAs more broadly.
- Some discussion of “innovation” v. “transformative” → reminder for FESAC TEC

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

SA4 – Develop & Advance Alternative Concepts for DEMO

- General agreement that the US should have a ‘Skunkworks’-like part of the program for range of reasons
  - High risk / high reward disruptive innovation opportunities
  - Educational aspect
  - Addressing outstanding plasma physics questions
- General agreement that the program should carry out merit-based, scientific and technological review of magnetic configurations including ongoing evaluation of progress and the potential for transformative breakthroughs

Austin

Slide directly from J. Menards Summary of Summaries presentation at Madison Workshop

WG4 – Review/Characterize Madison Key Strategic Elements

Consensus points:

- WG-4 did good job of characterizing Madison key strategic opportunities

- HTS magnet development should proceed.
  - Example arguments: favorably impacts a range of configurations, improves core plasma performance and/or stability, likely enables more compact devices

- Should increase emphasis on advanced divertor and PFC concepts.
  - Example areas of emphasis: international collaboration, liquid metals (needs technology development), and ultimately a divertor test tokamak/torus (DTT) for access to more DEMO-like divertor/first-wall conditions

- Should increase emphasis on steady-state high-performance regimes
  - Example research emphases: quasi-symmetric stellarator (US strength), advanced current drive techniques (primarily for tokamaks), further exploit existing US and international tokamak facilities

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WG5 – Integrate Fusion, Materials, Plasma Science

- Consensus on importance of broadening participation and integrating outside scientific communities not directly linked with MFE research (but could help in important aspects of MFE research)

- Having new initiatives for MFE with a more integrated national team approach is a mechanism for increased program integration going forward.

- Recommend that NAS investigate and/or comment on methods for breaking down barriers between BES and other offices in SC and FES to reduce stove-piping and to support cross-cutting efforts

- More work needed by this WG-5 to identify next steps, best approaches

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WG6 – Future Planning Activities – Moving beyond Austin

● Unanimous agreement that working groups should continue to meet to flesh out SAs, incorporating feedback from Austin

● Unanimous agreement that community planning process should continue beyond the NAS study

●Consensus that another community workshop should occur, if feasible, to synthesize the WG outputs and arrive at consensus on a prioritized list of SAs

●Consensus that process is producing valuable information for the program moving forward and is producing valuable guidance for FES

●Some groups recommend possible merging of some SAs (e.g., SA-1 with SA-2)

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Strategic Approach Working Groups Charge (1 of 2)

- Perform a gaps analysis (where required), assess risks, and develop a strategic roadmap with appropriately staged objectives for the strategic approach assigned to the working group.

- As part of this, the WG should discuss and enumerate those strategic elements discussed at the Madison and Austin meetings that have the potential for improving the prospects of success for this strategic approach.

- In addition, the WG should identify the benefits, risks, and challenges of *adopting this strategic approach as the primary pathway to achieve fusion energy in the next several decades*.

Pre-Austin

Strategic Approach Working Groups Charge (2 of 2)

Key Questions with Respect to NAS Charge F2*:

- **Impact of ITER:** What would the impact of access to ITER (or lack thereof) have on the strategic approach?
- **Strategic Elements:** What are the most impactful/important strategic elements from the Madison and Austin workshops (and other sources as necessary) enabling the strategic approach? In addition, what strategic elements require early attention to implement the overall strategic approach in a timely manner?
- **Scientific/Technology Underpinnings:** What new developments in theory, computation, modeling, experiment, diagnostics, and/or technology are critical to the success of the proposed strategic approach?
- **Decision Points:** What are the most important logical linkages (prerequisites, decision points) between strategic elements constituting the strategic approach? What are the key decision points within the strategic approach? i.e. when in the timeline is critical information needed for decisions on follow-on activities.
- **International Context:** In what areas would this strategic approach and the associated strategic elements support, complement, and potentially leapfrog activities in the broader international fusion energy R&D portfolio?

Pre-Austin