

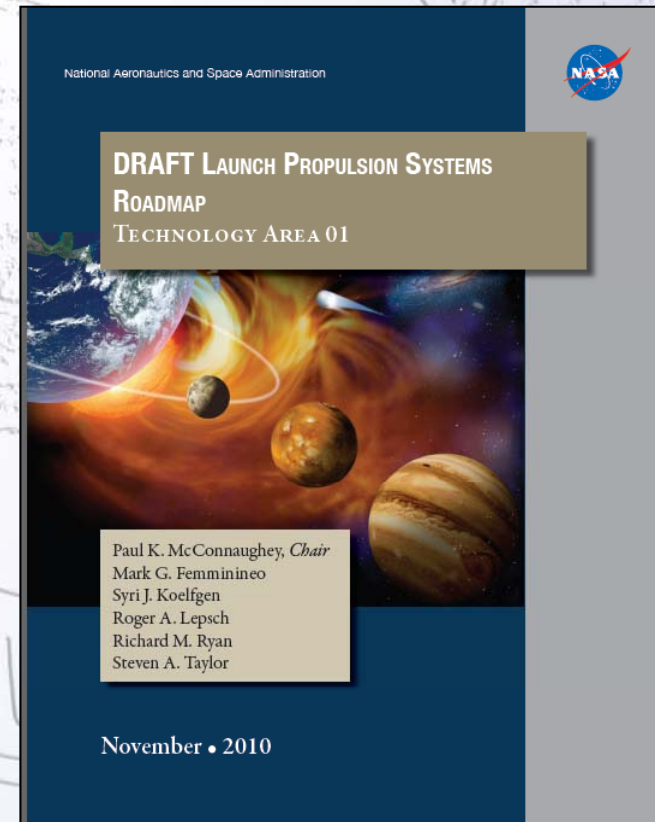


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TA-01 Launch Propulsion Roadmap Priorities

Russell Joyner
Technical Fellow – Pratt Whitney Rocketdyne
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The Questions Inside the Question

- **What should Our Nation (NASA) invest in to make biggest impact and why?**
 - Caveat – What have We invested in, What do We build off of to keep launch to LEO and Beyond affordable
 - We (the USA) should not throw this away
- **How do We do this and make the biggest impact**
 - **Increase capability for NASA space missions?**
 - **Lower the cost to do Missions?**
 - **Tangible benefits 20 years? – past 20 years?**

What We Know ?



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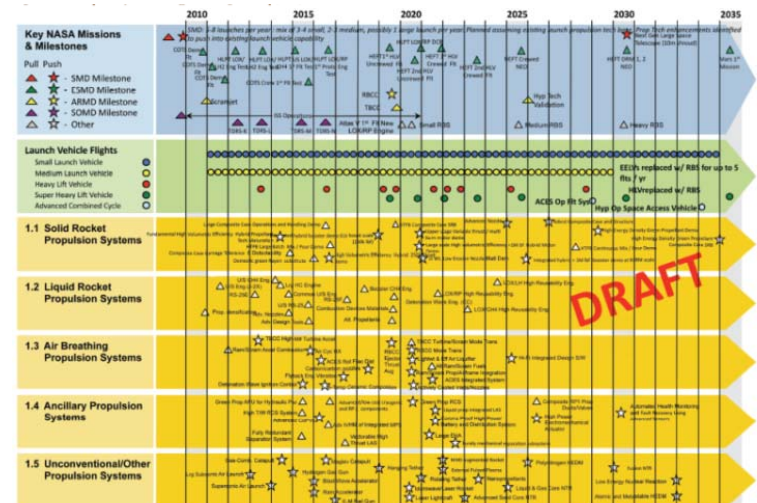
- **US has been global leader in propulsion – Affordability Is New Focus**
- **Other countries are Investing in propulsion to close the gap**
- **US needs to focus investments in propulsion development**
 - Currently non-existent
- **User desire to use off-the-shelf propulsion limits development**
 - Need to create balance – look for ways to create new value
- **All liquid LV's provide best value and flexibility**
 - Liquid boost, upper stages, and orbital stages are proven

Roadmap Review



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- **An extensive list Introduced – but limited funds available**
- **Considering nation’s budget challenges**
 - Demands prioritization based on contribution of the technologies towards a challenge goal – such as a human mission to Mars
 - Need to categorize: have-to-haves, nice-to-haves...and interesting science
- **NASA (We) must define a driving mission**
 - Create synergy with DoD and Commercial
- **For this prioritization process, PWR evaluated the roadmaps relative to a Mars mission challenge**



United States Leads in Cryogenic LOX/LH2 Space Launch Capability



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- **US has performed 133 successful launches on LOX/LH2, even more with current expendables**
 - Delta IV (all cryogenic) >10, Atlas V > 12 (U/S)
 - Proven technology for HLV per Saturn V & Shuttle
 - Reusability technology via Shuttle and DC-X
- **PWR has performed the only entirely commercial development of a large booster engine (RS-68)**
- **We (US) have capability now – leverage technology investment to create affordability**
- **Why do we think we want to give up leadership**
- **Focus technology investment on enhancing affordability**

United States Has Demonstrated LOX/RP Engine Technologies



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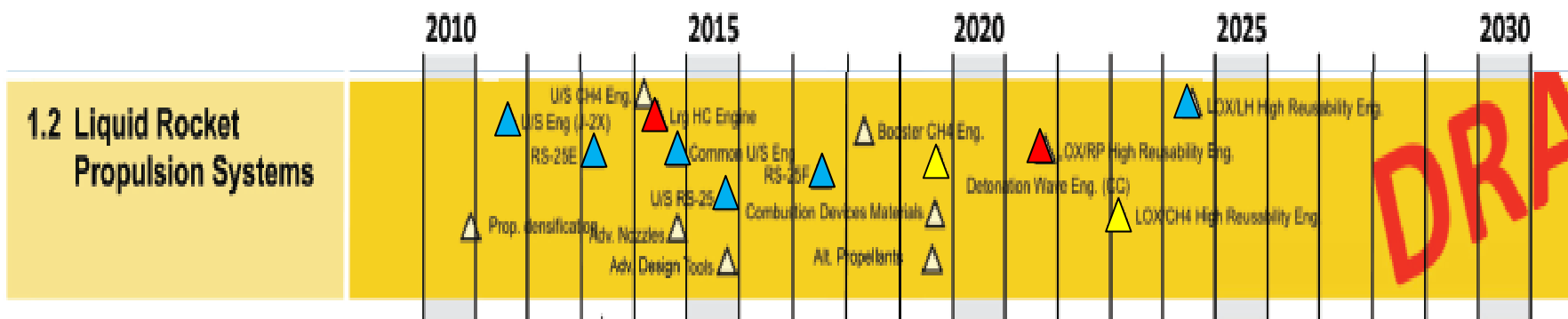
- **USA LOX/RP technology is demonstrated**
 - PWR has the best experience with LOX/RP Propulsion in United States; F-1, RS-27, MA-5, RD-180
 - > 1,300 launches, > 2,700 Engines
- **USA/PWR Has already demonstrated production of key technologies for large RP boosters**
 - Best early USA entry is co-produced RD-180
 - Cost effective, low risk path – restart/upgrade F-1A
- **Affordable low technical risk priority of large LOX/RP booster engines**
- **Prioritize technology investment in this area on cross-cutting items**
 - Low-cost materials and processes
 - System-level configurations
 - Integrated modules to Eliminate redundant systems

Need to Focus Liquid Rocket Technologies on Capability at Lower Cost



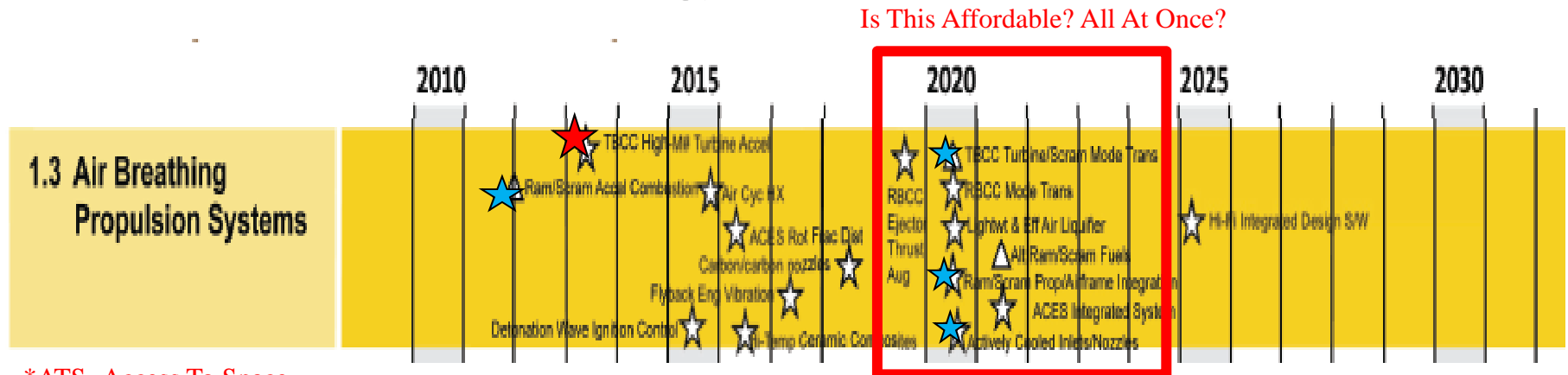
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- **Focus on Space Launch (SLS) capabilities that will be evolving**
 - Affordable high launch rate and heavy lift
- ▲ **Core SLS tech need is low cost cryogenic LOX/LH2**
 - Affordability focused technology enhancements building off investments made: SSME (RS-25), J-2X
- ▲ **LOX/HC (high-density/thrust, low Isp) focus technologies on what the physics show – sea level boost for larger payloads**
 - Strap-on boost for growth as NASA missions evolve
- **Detonation engine immature for affordability focus**
- **LOX/CH4 technology for boost needs to show payoff**



Need to Focus Airbreathing ATS* Technology Investment On Demonstration of Robustness

- Focus technologies on small space launch demonstrators
 - Prove “vision” of robust operability for air breathing ATS
- ★ Focus on benefit of combined cycles with off-the-shelf elements to create affordable demonstrators for architectures
 - Architectures require cost like commercial systems with military-type robustness
 - Build off military/space technology using off-the-shelf for low-speed (<M3)
 - Focus on technologies for Ram/Scram for mode transition for TBCC and RBCC
- ★ RBCC technology can build off TBCC (e.g. Ram/Scram) & TA-01 liquid rocket (share technology)



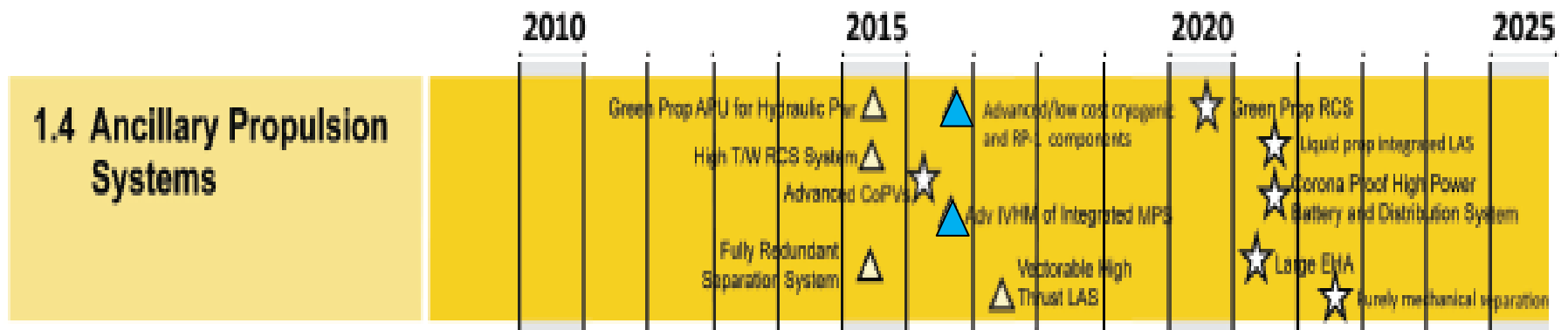
*ATS=Access To Space

Need to Focus Technology Investment On Mission-Necessary Capabilities



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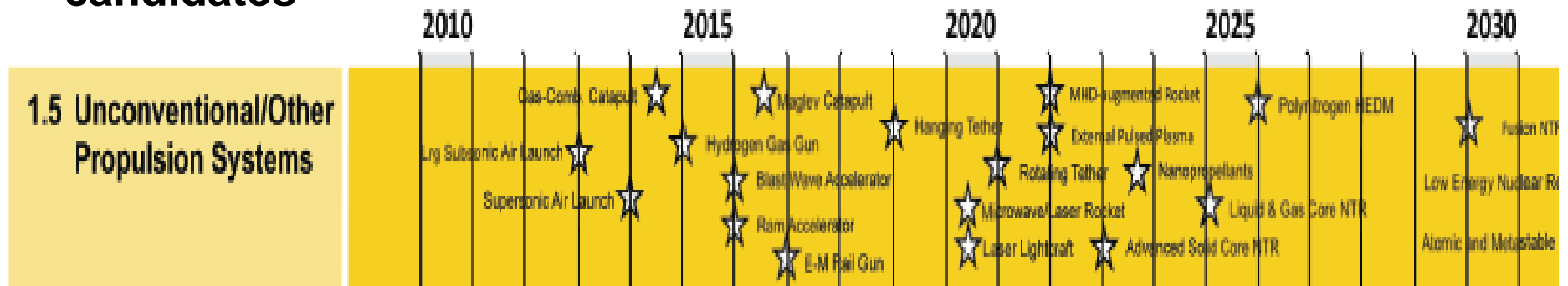
- **Focus on technologies to either enable a necessary capability or improve system / mission affordability**
 - “Advanced / low cost cryogenic and RP components” is a good start (can expand beyond individual component work)
 - “Advanced IVHM” likely required for complex systems / large-scale / long duration missions





Mostly Low TRL items

- Focus efforts on a select few high-pay-off, revolutionary items
- Items should be selected based on a risk-based benefits-assessment approach
 - Quantified benefits
 - Projected development cost (to completion) & risk
- Too many high risk concepts to “peanut-butter” the funding – would prohibit meaning progress on many vs. fully evaluating best candidates



Summary



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- **NASA Roadmap Is Comprehensive, Now We Need to Extract the Technologies that Provide More Affordable Capability for Science and Human missions**
- **Considering NASA's (and the Nation's) budget challenges prioritization must be based on the contribution of the technologies towards accomplishing a significant goal – such as a Human Mission to Mars – A “Visionary Goal” – Not A Waypoint**
 - **NASA has to define this type of mission**
- **Focus should be on leveraging historical NASA investments to enable a reliable SLS and In-space Systems – with low development risk (and hence low cost risk)**
- **Focus on affordability enhancement technologies**
 - **Work Cross-cutting Affordability Technologies NOW**
- **Provide a focus level of funding for longer-term capabilities**
 - **Prioritize towards some future mission**