Chapter 7: Research Goals and Plans for Wave Heating and Current Drive
[Section coauthors in green, **with lead coauthor in bold**]

7.1 Overview of Goals and Plans [**Taylor**]

7.1.1 Research Thrusts:

7.1.1.1 Develop HHFW and EC/EBW heating and current drive for fully non-inductive plasma start-up and H-mode sustainment
7.1.1.2 Optimize HHFW current drive in HHFW and HHFW+NBI H-mode plasmas
7.1.1.3 Determine the validity of advanced RF codes for NSTX-U RF-heated plasmas and use these codes to predict RF performance in FNSF and ITER

7.1.2 Research Needed to Enable these Thrusts:

7.1.2.1 Assess HHFW interaction with neutral beam fast-ions, and develop capability to heat high-power NBI H-modes with HHFW
7.1.2.2 Mitigate HHFW power losses in scrape off layer of H-mode plasmas
7.1.2.3 Model and implement ECH/EBWH to support plasma startup and local heating and current drive in NBI H-mode
7.1.2.4 Develop advanced RF codes that include SOL, realistic antenna geometry and accurately model interaction between the wave fields and NBI fast-ions

7.2 Research Plans:

7.2.1 Years 1-2:

7.2.1.1 Assess performance of 12-strap, double-feed antenna and compatibility with NBI H-modes [**Hosea**, Perkins, Wilson]
7.2.1.2 Evaluate, study and mitigate RF power flows in the SOL and to the divertors in the H-mode regime [**Hosea**, Perkins, Wilson]
7.2.1.3 Heat I_p ~ 300 kA plasma with HHFW power to achieve sustained 100% non-inductive (NI) H-mode, and non-inductively ramp I_p with HHFW power: [**Taylor**, Raman]
7.2.1.4 Study HHFW interaction with NBI fast-ions and model with advance RF codes [**Taylor,** Podestà, LeBlanc]

7.2.2 Years 3-5:

7.2.2.1 Test high-power ECH system for plasma start-up - assess impact on closed-flux current achieved, discharge pulse-length, and non-inductive fraction [**Taylor**, Raman]
7.2.2.2 Utilize HHFW to assist start-up plasma formation and compare to ECH [**Taylor**, Raman]
7.2.2.3 Assess impact of HHFW electron heating on NBI current ramp-up [**Taylor**, Raman]

7.2.2.4 Simulate and/or mock-up HHFW antenna performance using a reduced number of antenna straps [**Hosea**, Perkins, Wilson]
7.2.2.5 Test reduced-strap HHFW system and optimize plasma start-up, ramp-up, and sustainment during NBI H-mode [**Hosea**, Perkins, Wilson]
7.2.2.6 Pending successful EBW heating results project EBW CD performance to a FNSF/CTF [**Taylor**]

7.3 Summary Timeline for Tool Development Needed to Achieve Research Goals

7.3.1 Theory and Simulation Capabilities: **[Phillips]**

7.3.1.1 AORSA-3D full-wave code for HHFW modeling, including SOL and realistic antenna model [**Green**]
7.3.2.2 AORSA/ORBIT-RF full-wave/Monte-Carlo code for HHFW modeling of NBI plasmas [**Choi**]
7.3.2.3 TORIC full wave code, with SOL model, and SPIRAL code for HHFW modeling [**Phillips**, Valeo, Bertelli, Bonoli, Wright, Kramer]
7.3.2.4 GENRAY ray tracing modeling with SOL model and edge fluctuations for HHFW modeling [**Phillips**, Bertelli, Harvey, Bonoli]
7.3.2.5 Full finite orbit width CQL3D Fokker-Planck code for HHFW modeling of NBI plasmas [**Harvey**, Petrov]
7.3.2.6 Use of DC (Diffusion Coefficient code) for NSTX-U [**Harvey**]
7.3.2.7 GENRAY and TORBEAM ray tracing for ECH modeling [**Harvey**, Bertelli]
7.3.2.8 GENRAY/CQL3D for EBW heating and current drive modeling [**Harvey**]
7.3.2.9 Upgrade NUBEAM with RF operator for HHFW modeling of NBI plasmas [**Green**]

7.3.2 Diagnostics:

7.3.2.1 Fast IR for SOL power losses [**Hosea**, Perkins, Wilson]
7.3.2.2 Measurements of SOL E-fields during edge power loss [**Hosea**, Perkins, Wilson]
7.3.2.3 Magnetic and Langmuir probes in protective tiles above and below antenna to document RF power flow to divertor for comparison to advanced RF codes [**Hosea**, Perkins, Wilson]
7.3.2.4 Diagnostic enhancements to measure fast-ion distribution from HHFW acceleration [**Podesta**]
7.3.2.5 10-40 GHz edge reflectometer for HHFW [**Taylor**, Ryan]

7.3.3 Other Facility Capabilities:

7.3.3.1 Implement compliant attachments between antenna current straps and RF feedthroughs to withstand 4x increase in disruption loads [**Hosea**, Ryan, Perkins, Wilson]
7.3.3.2 Modifications to NBI armor/limiter to allow HHFW operation with high NBI power [**Hosea**, Ryan, Perkins, Wilson]

7.3.3.3 Implement EHO and/or *AE antenna [**Hosea**, Fredrickson, Goldston]
7.3.3.4 Modify HHFW antenna to have reduced number of straps [**Hosea**, Ryan, Perkins, Wilson]
7.3.3.5 Implement 28 GHz (1-2 MW, 1-5s) EC/EBW heating system with fixed horn [**Taylor**, Ellis]
7.3.3.6 Upgrade 28 GHz EBW antenna to metal steerable mirror for EBW heating and current drive studies [**Taylor**, Ellis]