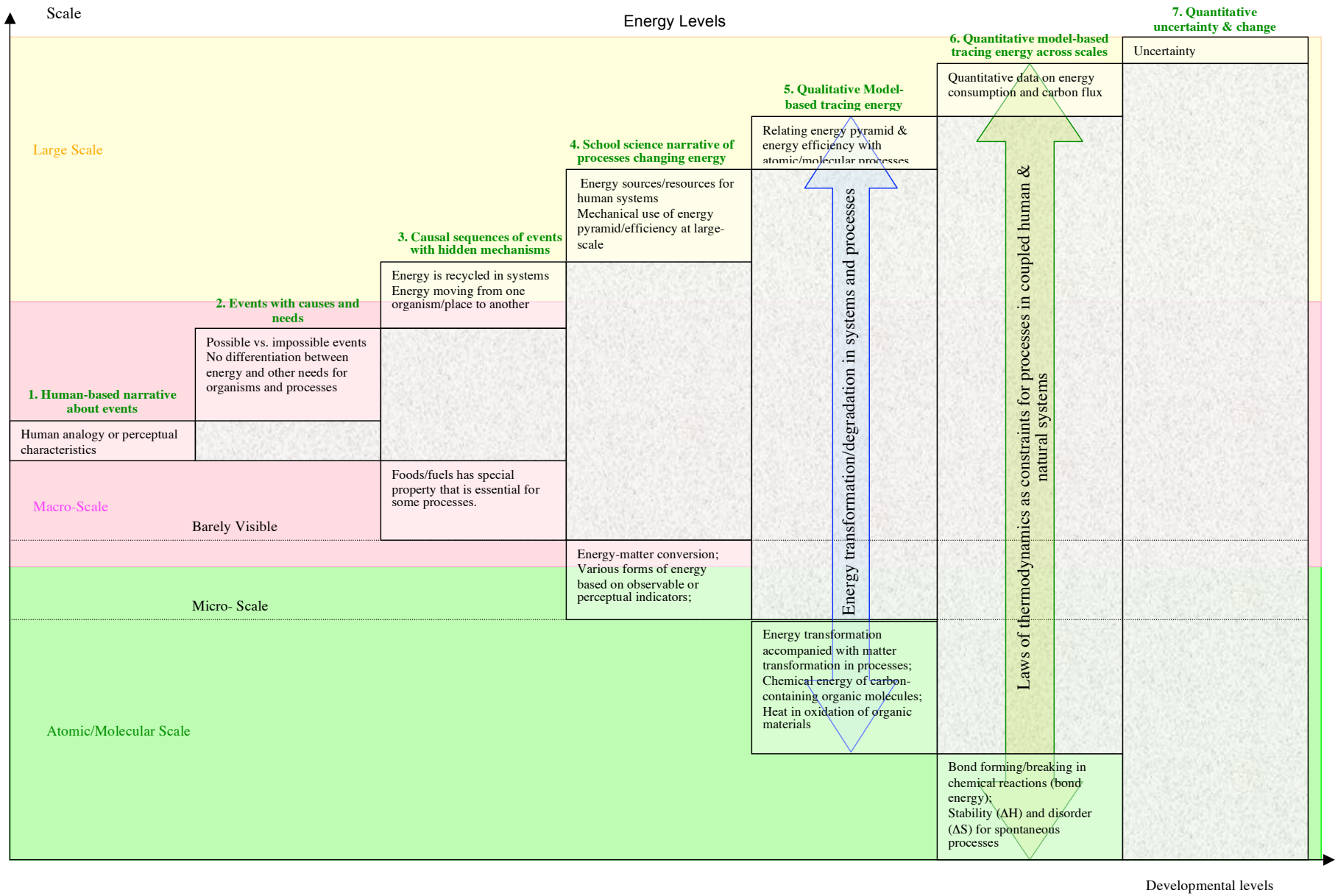
Scale
Energy Levels
7. Quantitative uncertainty & change
Uncertainty
6. Quantitative model-based tracing energy across scales
Quantitative data on energy consumption and carbon flux
5. Qualitative Model-based tracing energy
Relating energy pyramid & energy efficiency with
4. School science narrative of processes changing energy
Energy sources/resources for human systems
Mechanical use of energy pyramid/efficiency at large-scale
3. Causal sequences of events with hidden mechanisms
Energy is recycled in systems
Energy moving from one organism/place to another
2. Events with causes and needs
Possible vs. impossible events
No differentiation between energy and other needs for organisms and processes
1. Human-based narrative about events
Human analogy or perceptual characteristics
Large Scale
Macro-Scale
Barely Visible
Foods/fuels has special property that is essential for some processes.
Micro- Scale
Energy-matter conversion;
Various forms of energy based on observable or perceptual indicators;
Energy transformation/degradation in systems and processes
Laws of thermodynamics as constraints for processes in coupled human & natural systems
Energy transformation accompanied with matter transformation in processes;
Chemical energy of carbon-containing organic molecules;
Heat in oxidation of organic materials
Atomic/Molecular Scale
Bond forming/breaking in chemical reactions (bond energy);
Stability (ΔH) and disorder (ΔS) for spontaneous processes
Developmental levels

	Level Description	Energy in systems	Energy in processes
7	**Quantitative uncertainty & change.** *Uncertainty of environmental issues* The student recognizes the uncertainty around the issue of global warming and makes decisions and judgments based on systemic analysis of qualitative and quantitative information from multiple media.	Recognizes the uncertainty of the issue of global warming and takes it into account when analyzing quantitative and qualitative information from multiple media sources. (e.g. quantitative risk assessment, error bars)	
6	**Quantitative model-based tracing energy across scales** *Processes constrained by the first and the second laws of thermodynamics.* The student *analyzes processes (chemical reactions) in terms of bond breaking and forming*. So s/he can use the concept of bond energy to qualitatively identify exothermic or endothermic changes and to quantitatively calculate the amount of energy released/absorbed in the processes. The student understands the quantitative data about energy consumption, carbon emission, and carbon sequestration.	Analyzes processes (photosynthesis, cellular respiration, combustion) in terms of bond breaking and forming. Recognizes that energy is required to break chemical bonds and that energy is released when bonds form. Uses the concept of bond energy to qualitatively identify exothermic or endothermic changes and to quantitatively calculate the amount of energy released/absorbed in the processes. Explains spontaneous chemical and physical processes in terms of stability (ΔH) and disorder (ΔS). Uses entropy (ΔS) to constrain large-scale processes. Understands quantitative data about energy consumption, carbon emission, carbon sequestration, and relationships among them. (Pre-requisite understanding is the qualitative understanding of the energy transformation and matter transformation in chemical processes – level 5.)	
5	**Qualitative Model-based tracing energy across scales.** *Systemic accounting for energy transformation & degradation in processes.* The student understands *processes (chemical reactions) as atom re-arrangement*. So s/he can use both energy transformation and degradation to constrain processes. But the student cannot correctly account for energy in bond breaking and forming in chemical reactions. The student recognizes atomic/molecular processes as the foundation for large-scale principles such as energy pyramid and energy efficiency.	Distinguishes energy consistently from matter at atomic/molecular scale: Explains and compares energy concentration of carbon-containing organic molecules (e.g. hydrocarbons, carbohydrates, and lipids) in terms of chemical bonds. Identifies and distinguishes energy sources and resources (non-renewable and renewable) for human systems. Identifies heat as the form of energy unavailable to any organisms and being associated with every process of energy transformation.	Distinguish and explain energy transformation and matter transformation in processes of generation and oxidation of organic materials. Recognizes heat is lost in every process of energy transformation (e.g. After respiration or combustion, all energy originally in the organic materials dissipates into environment as heat.) Recognizes energy degradation in oxidation of organic materials is the theoretical foundation for energy pyramid and energy efficiency and traces energy through sequences of processes with degradation
4	**School science narratives of processes changing energy.** *Energy as source and constraint.* The student understands of *molecular composition and structure of matter*. So s/he can successfully identify energy sources across a range of processes. But, the student tends to use matter-energy conversion to reason processes. The student recognizes relationship among organisms in terms of *biological processes at cellular scale* without identification of the underlying chemical reactions at atomic/molecular scale. S/he may also mechanically apply large-scale principles such as energy pyramid/efficiency to events without recognizing that these concepts are related to atomic/molecular processes.	Associates chemical energy with key organic substances in environmental systems and recognizes light as the only energy source for plants. Does not consistently distinguish between energy and matter.	Traces energy through food chains and webs, digestion, and growth in terms of energy moving from one place/organism to another without identification of underlying chemical processes (organic carbon generation or oxidation) Correctly identifies energy sources for events without recognizing energy transformation in processes (e.g. Energy goes from one place/organism to another without transformation; energy-matter conversion.) Mechanically applies large-scale principles such as energy pyramid/efficiency to events without recognizing that these concepts are related to atomic/molecular processes
3	**Causal sequences of events with hidden mechanisms.** *Energy as resource but not constraint.* The student holds some differentiation between resources that supply energy — eg. foods and fuels — and other resources such as matter and conditions, but s/he identifies energy sources based on *macroscopic experience* instead of atomic/molecular structure of materials. As the result, his/her success in identifying energy sources is highly context-dependent. The student recognizes and describes the *macroscopic interrelationship* among organisms in terms of causal sequences of events without identification of any underlying biological processes at cellular level.	Identifies light energy, kinetic energy, heat, sound energy, and electrical energy based on visible/perceptual indicators. Recognizes that certain classes of materials (foods, fuels) can serve as energy sources based on macroscopic experience, but cannot consistently identify energy source for organisms. (e.g. light and nutrients are energy sources for plants; foods and water are energy source for animals.) Does not consistently distinguish energy from matter.	Recognizes that events or processes (e.g. organism growth, moving machines at home, running cars) require energy as resource, but does not use principles about energy (energy conservation & energy degradation) as constraints for processes. Recognizes and describes the macroscopic interrelationship among organisms in terms of causal sequences of events without identification of any underlying biological processes (photosynthesis, cellular respiration, decomposition) at cellular level.
2	**Events with causes and needs** The student reasonably separates between possible and impossible events and processes and is aware of "needs" of processes and organisms, but s/he does not distinguish between energy with general need.	Consistently distinguishes possible from impossible events, but does not use energy concept to reason why certain event are possible and others are impossible. (e.g. In order to watch TV, you always need to plug in – but do not reason why.) Recognizes needs for organisms (e.g. organisms require light/foods for living) and causes for processes (e.g. Car needs gasoline to run and machines need plugged in to work), but does not use scientific concepts such as matter and energy for reasoning. Energy is not differentiated from other needs for organisms or processes.	
1	**Human-based narrative about events** The student describes events in terms of personal causation and effects—how to make things happen	Use human analogy instead of energy concept to classify materials or reason macro-scale events. Does not consistently distinguish between possible and impossible events	