Measured Demonstration of Low Carbon Success:

Demonstration Project of a Carbon-Neutral Energy System

Understanding the Low Carbon Economy
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Scope of Presentation

- Description of the HARI project
  - Existing RE system at West Beacon Farm
  - Intermittency and grid balancing
  - Energy storage
  - The role of hydrogen
  - New additions for the HARI project
  - System Integration
  - System modelling
  - Ongoing work and future plans for WBF
- Wider issues that follow from the HARI project
  - Hydrogen for transport applications vs. electricity storage
  - The Hydrogen Economy
- Conclusion

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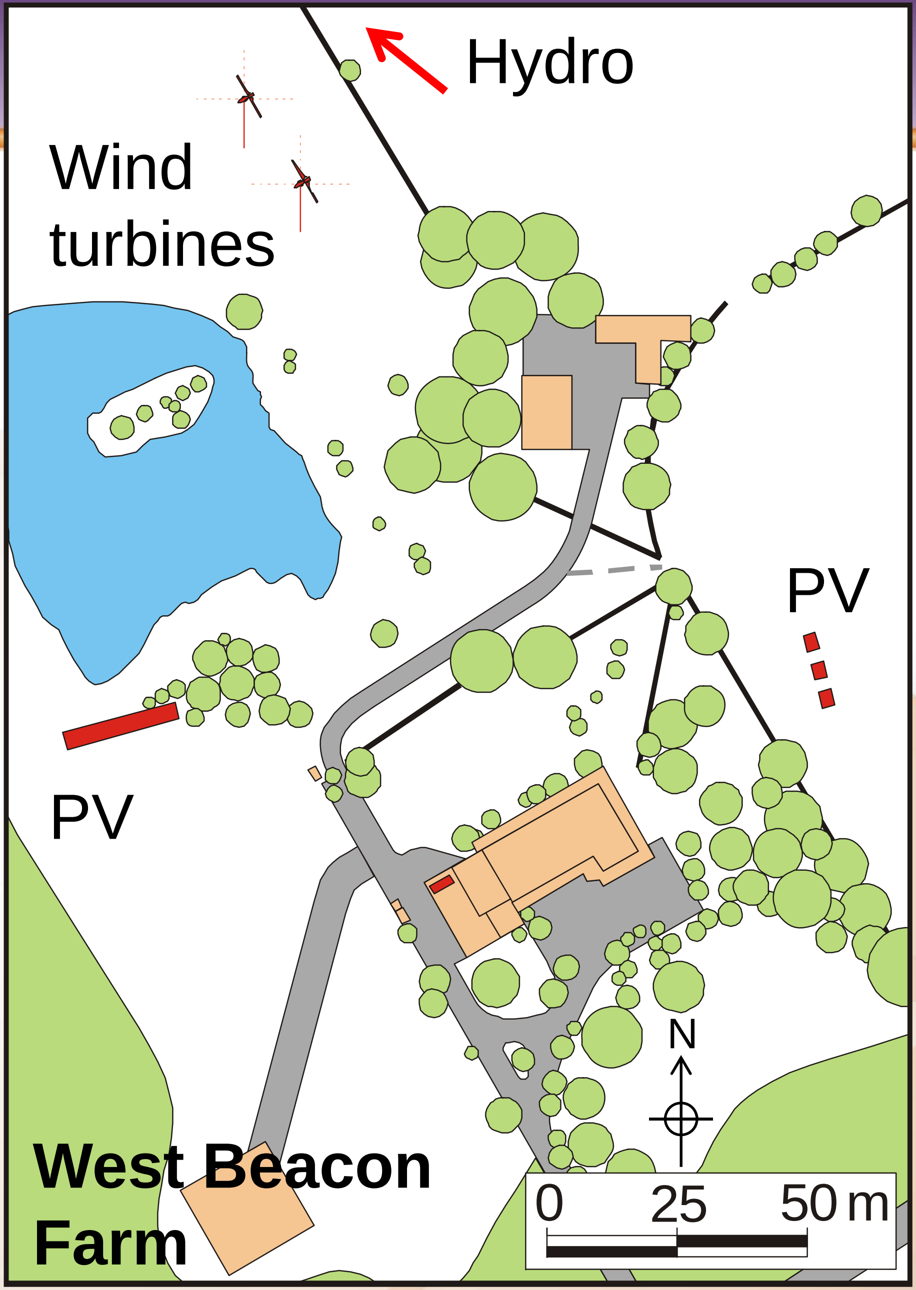
HARI Project

- Hydrogen and Renewables Integration (HARI) project
  - Existing renewables
  - Wish to create a stand-alone sustainable energy system
    - Requires storage to achieve autonomy from grid
      - ~ Hybrid battery-hydrogen storage system
    - Develop and validate models for
      - ~ Sizing of components
      - ~ Designing similar systems for wider deployment
      - ~ Strategic models also developed
  - Demonstrate the principles of the ‘hydrogen economy’
    - Remote/island, stand-alone systems (early adopters)
    - Implications for national power systems (long term)

Existing System

- 2 x 25kW wind turbines

- 13kWp photvoltaics
- 3.2kW hydro



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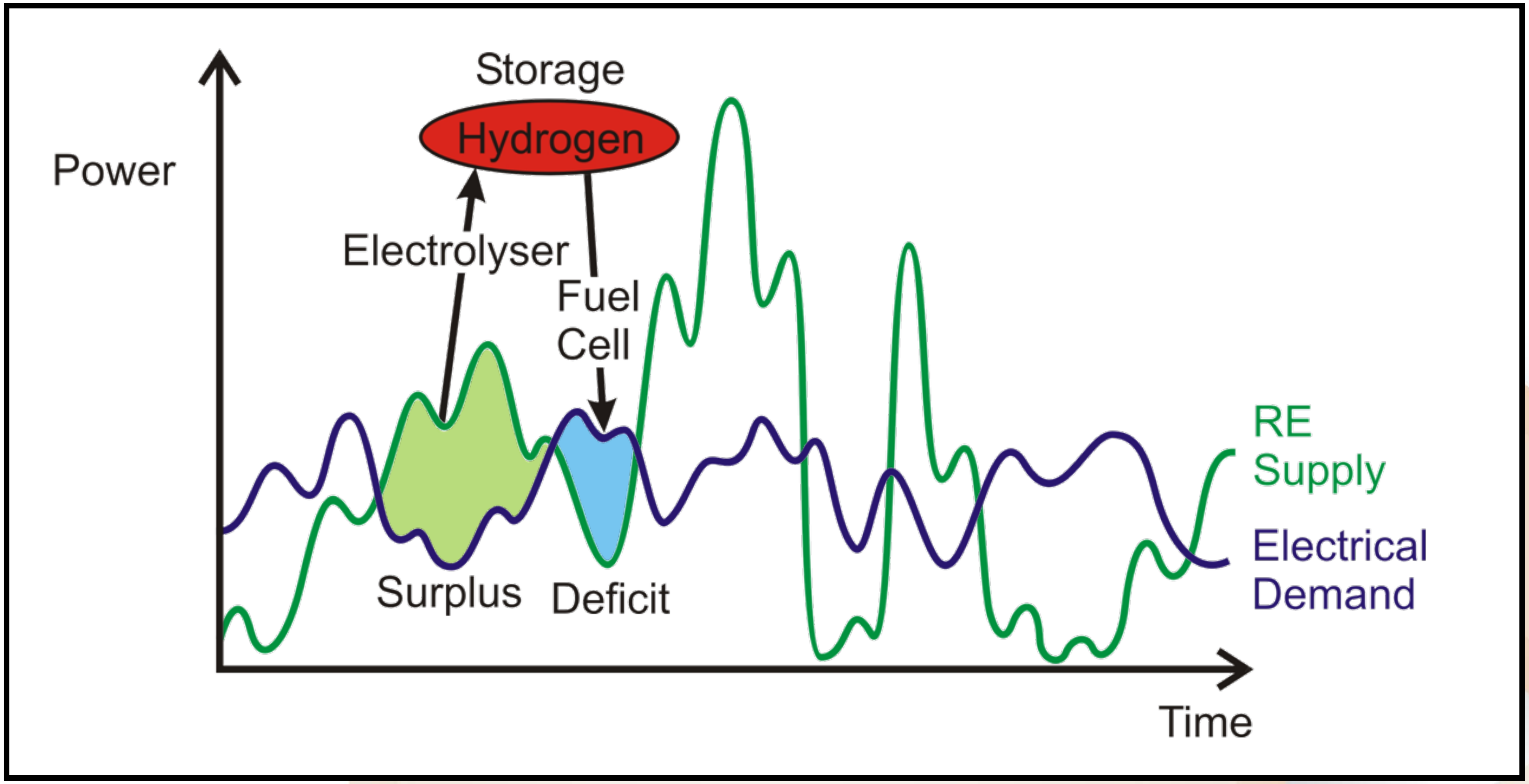
Intermittency and Grid Balancing



- RE (and nuclear) supply cannot be modulated to match demand
- Energy storage is needed to balance varying supply with varying demand

Energy Storage Options

- Electricity storage can be achieved by many technologies
  - e.g. flywheels, supercaps., batteries, comp. air, pumped hydro, flow cells, hydrogen, etc.
- Advantages of hydrogen
  - Better for long timescales (from 4 days up to inter-seasonal)
  - Better for large capacities
    - Lower cost
    - Smaller footprint
  - Dissociation of charge/discharge rates and store capacity
  - Flexibility means widely applicable (e.g. transport fuel, portable and stationary power)
  - No harmful emissions
  - Can ‘float’ indefinitely
- Disadvantages of hydrogen
  - Low round-trip efficiency
    - Meeting the challenge of high capacity, long timescale energy storage comes at a high energetic cost
    - But there is a lack of alternatives (advanced batteries?, flow cells?)
    - Scope for improvement of efficiency
  - Technical advances and cost reductions needed

How Does Hydrogen Store Energy?

- When surplus energy is available
  - Electricity is fed into an electrolyser
    - Splits water into hydrogen and oxygen

- Storage period
  - Hydrogen is stored
    - As a compressed gas, super-cooled liquid, solid-state (e.g. hydrides), chemical (e.g. methanol, ammonia)

- When energy is required
  - Electricity is generated by a fuel cell (or ICE)
    - Hydrogen and oxygen recombine to make water

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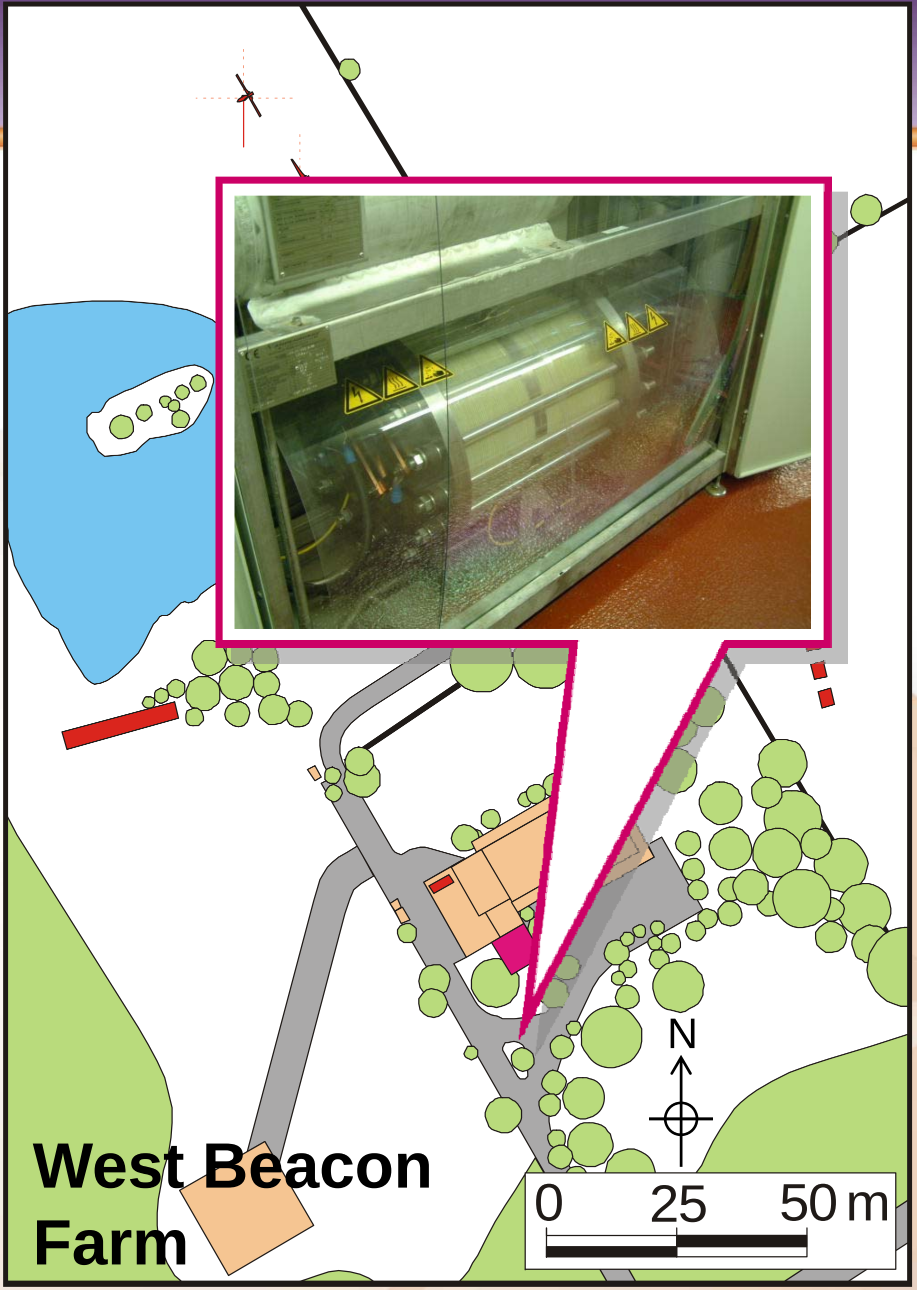
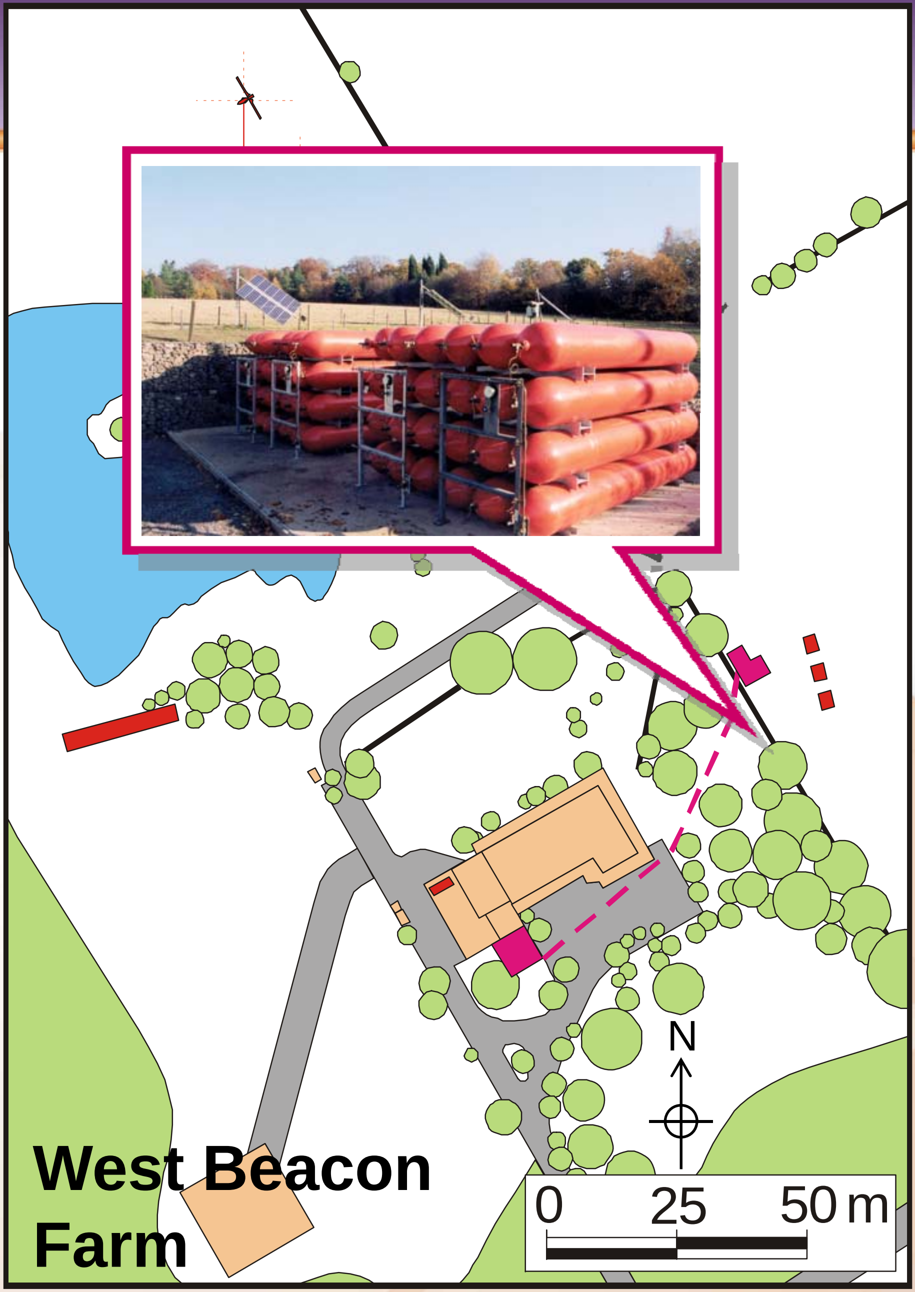
New Components

- Electrolyser
  - Hydrogenics (previously Stuart Energy / Vandenborre)
  - Alkaline
  - 36kW module
  - 25bar (nominal)
  - 8Nm^3/h
  - 99.999% H_2 purity



New Components

- Hydrogen store
  - BOC
  - Pressurised gaseous H_2
  - 48 steel cylinders (0.475m³ water volume each)
  - Up to 137bar
  - 2856Nm^3
  - Approximately 3.8MWh equiv. (electricity production via FCs)



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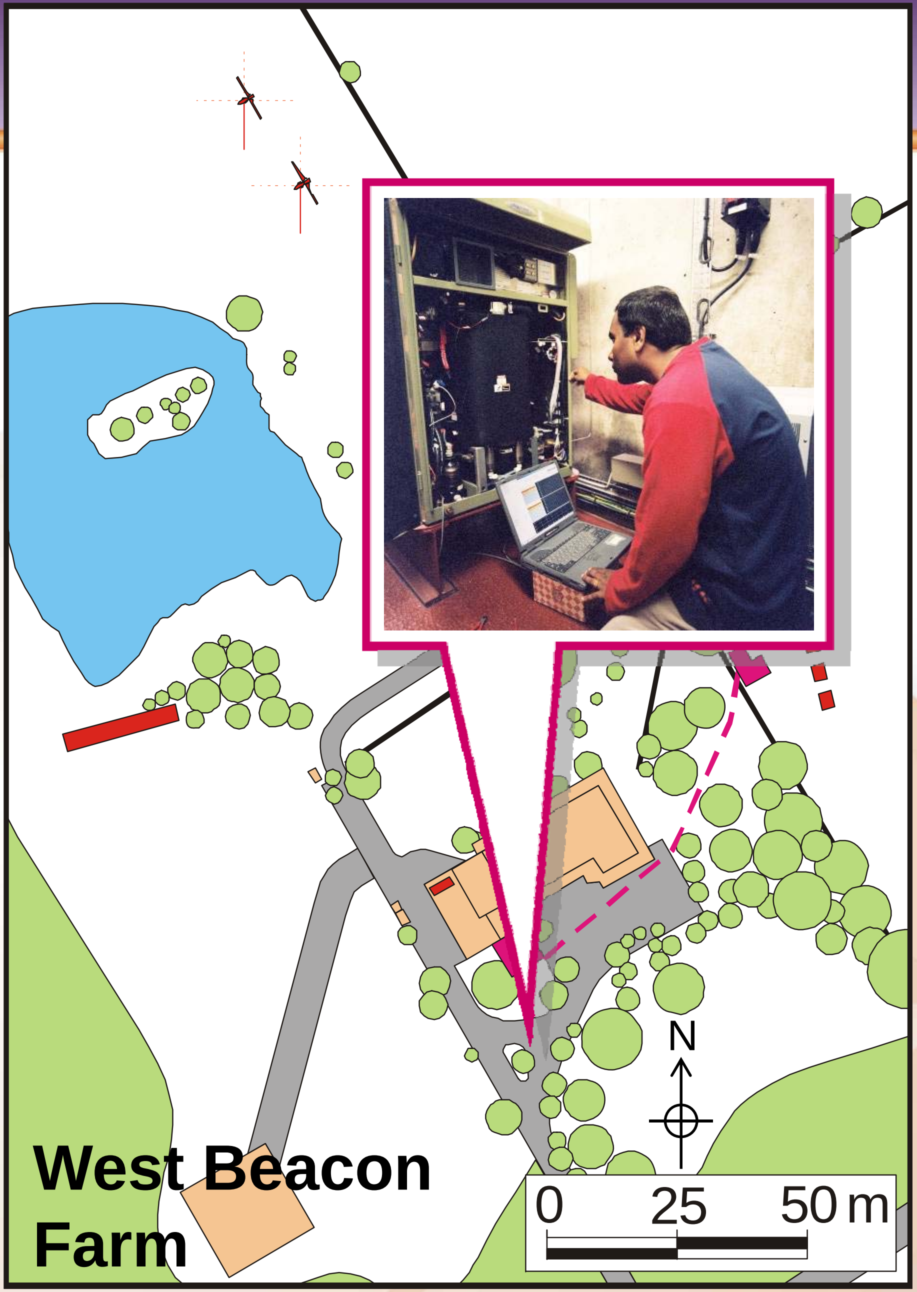
New Components

- Fuel cells
  - Intelligent Energy
    - PEM
    - 2kW (4kW peak)
    - CHP
  - Plug Power
    - PEM
    - 5kW
    - Will be converted to CHP



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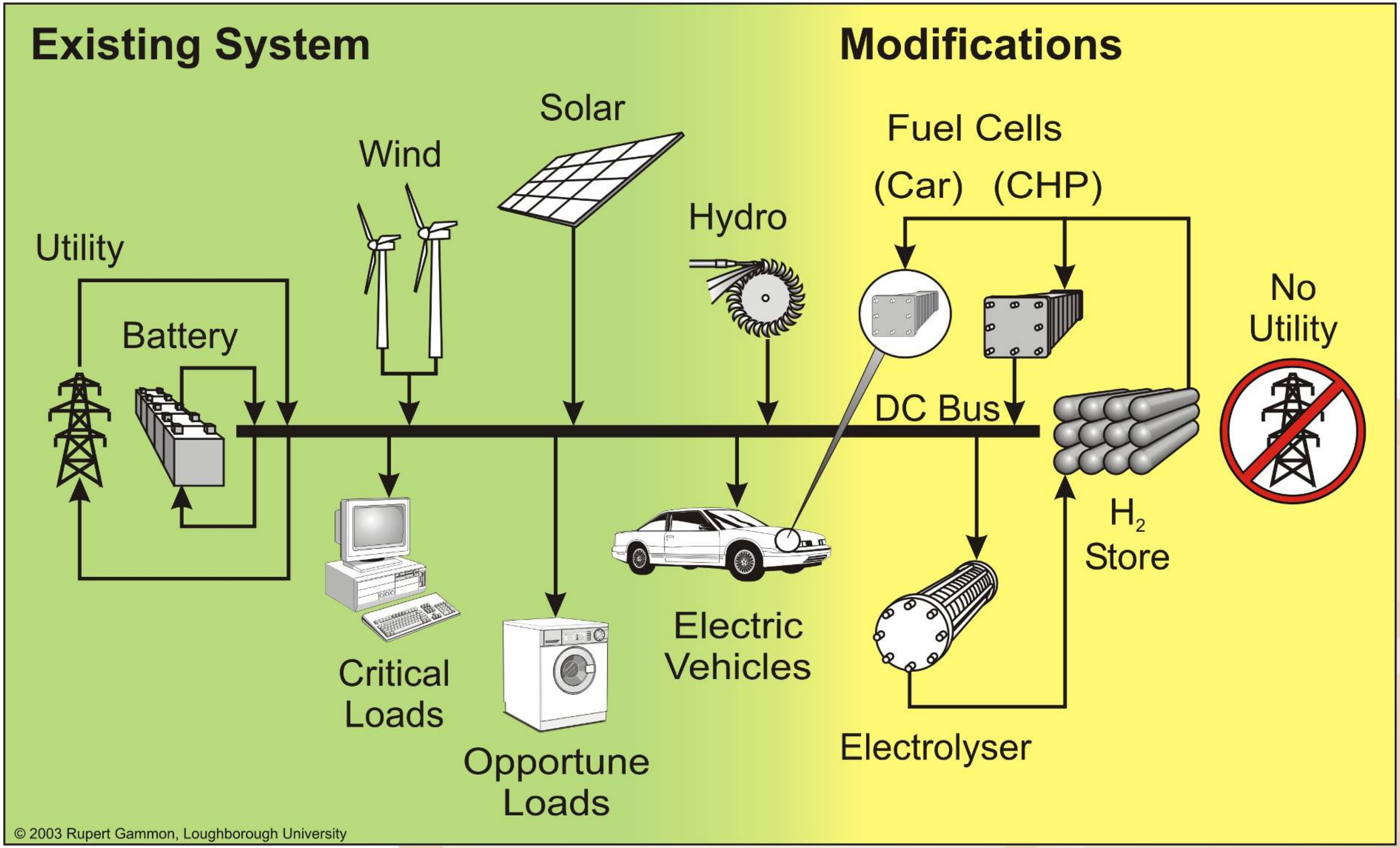
Integration of System



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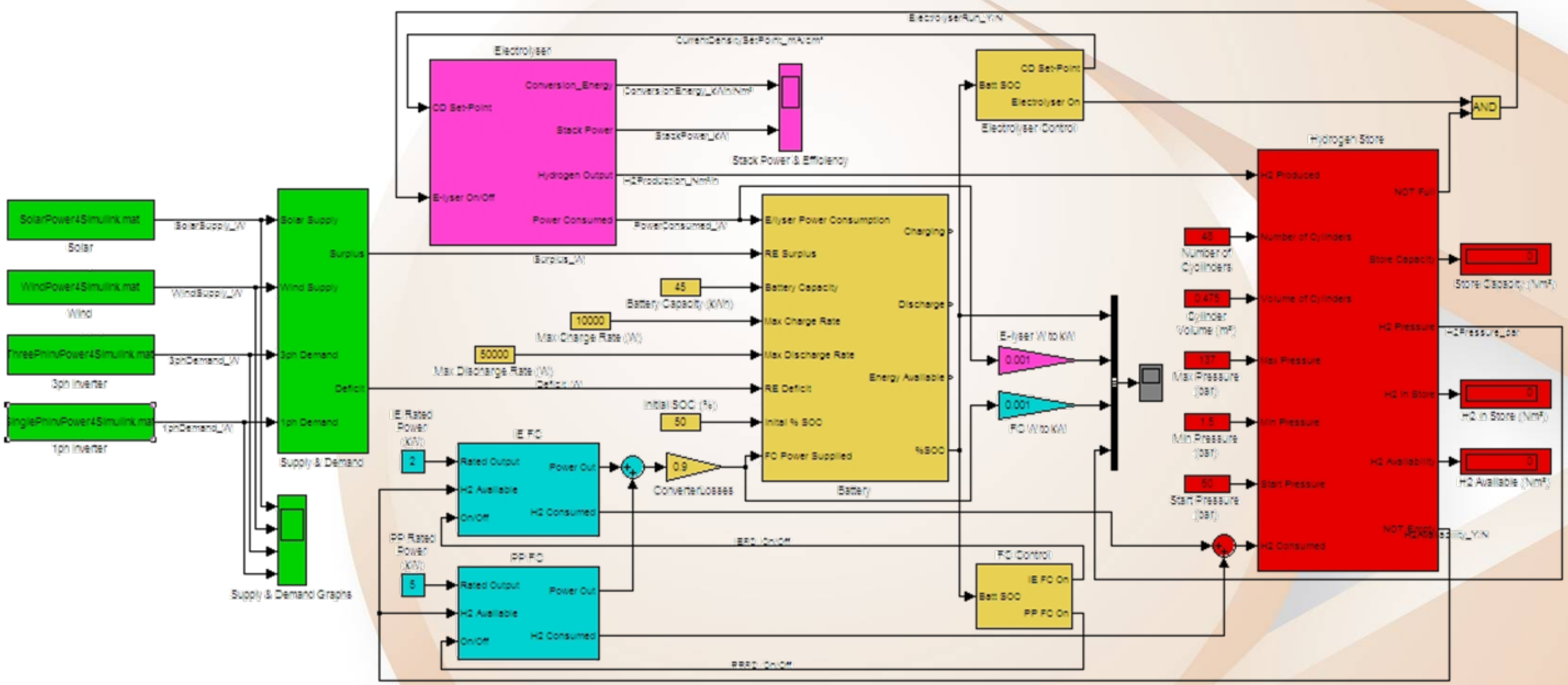
Rationalisation of Electrical System

- Batteries required
  - Short-term storage (complementary to H_2)
  - Electrolyser control
  - System control based on SOC
- Conversion of wind turbines to run off-grid
  - Frequency control by power electronics
  - Excitation of magnetic fields (in induction generators)
- High Voltage DC bus system – recently abandoned
  - 560-750V
    - Rectified 3-phase
    - Standard power electronics
  - High temperature NiNaCl batteries
    - Allow high voltage
    - Designed for vehicles
    - High self-discharge
    - Not compatible with HARI requirements (esp. 100% recharge requirement)
- Medium Voltage DC bus System – currently being introduced
  - 110-140V
  - Lead-acid batteries

System Modelling

- System model in Matlab Simulink
  - Validated against real-world operation
  - From weather to loads (via REs and H_2)
  - Can be used for system design (…anywhere!)



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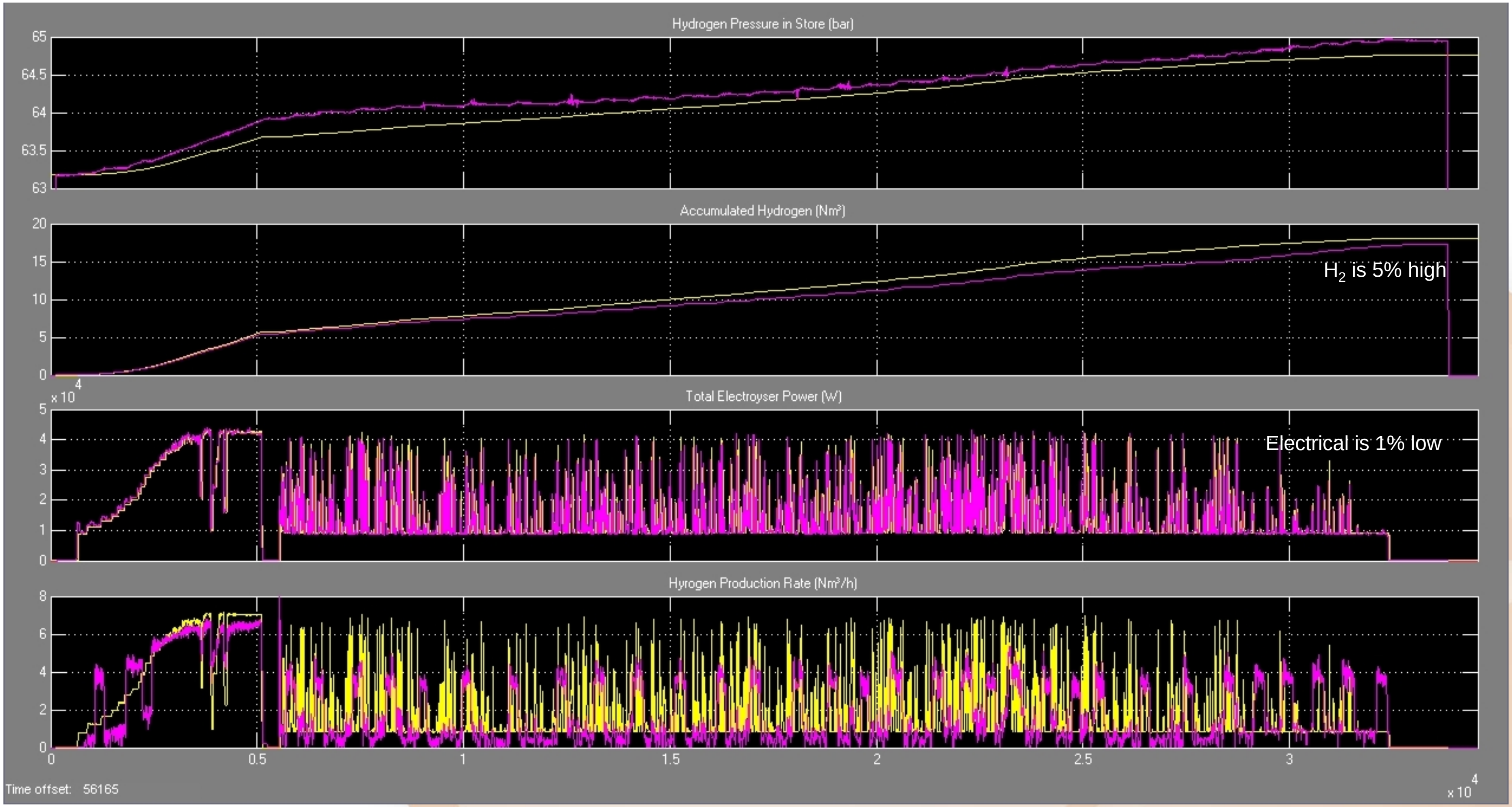
Model Verification

- Electrolyser test run
  - Predicted by model (yellow) compared to measured (magenta)



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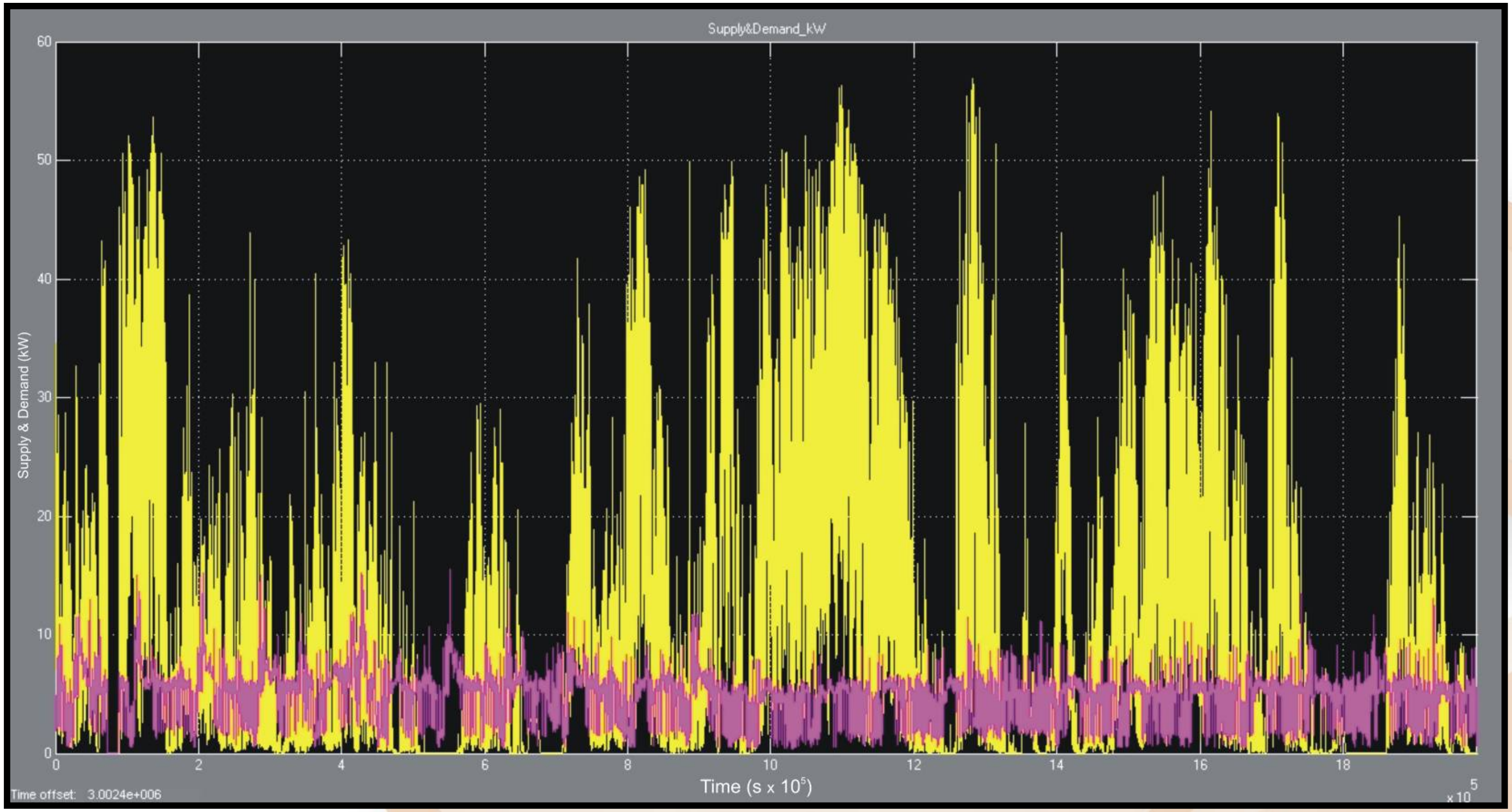
Energy Balance

- Data from HARI Project
  - Yellow = RE Supply, Magenta = Electrical demand



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Future Plans

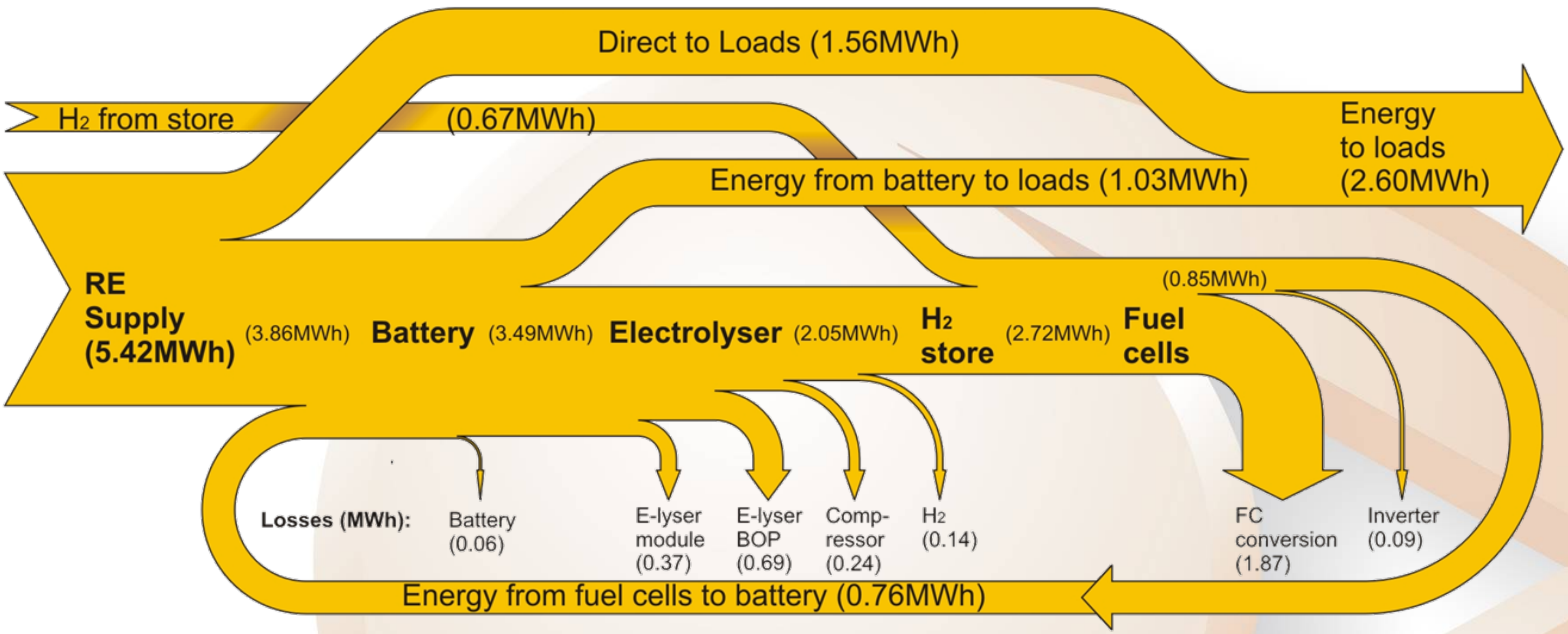
- Improve energy efficiency
  - Heat capture (CHP/CHF)
  - Recycle water (use RO less)
  - Power electronics (modularise, part-load efficiencies)
  - Standing losses (reduce/eliminate)
  - Insulation
- Metal-hydrides (Birmingham University)
- Hydrogen refuelling station
  - Important to include transport elements into system
  - Dual- fuel (H2 & petrol) Prius, FC range-extender in electric car
  - Sale of ‘green’ hydrogen
- ‘Tandem’ cells
  - Photovoltaics & electrolysis all-in-one
  - Does not perform load balancing role, only H_2 production
- Further modelling and analysis

RE Powered Electrolysis

- Existing systems designed for continuous (steady-state) mains supply
  - Pressurised (complex, expensive, leaky & less efficient)
  - Dynamic RE supply damages components and wastes energy in **pressurised** electrolysers
- Low pressure systems (with external compression) are preferable for REs
  - Simplicity, reliability & low cost necessary for early adopter markets
  - Internal pressurisation ***not*** “for free” anyway
- Waste heat capture (CHF) should be employed to increase overall efficiency
- BOP losses
  - Power electronics
- Operational range
  - Turndown to nearly zero

HARI System Efficiency

- First phase: get system working



- Second phase: get system working <u>*efficiently!*</u>

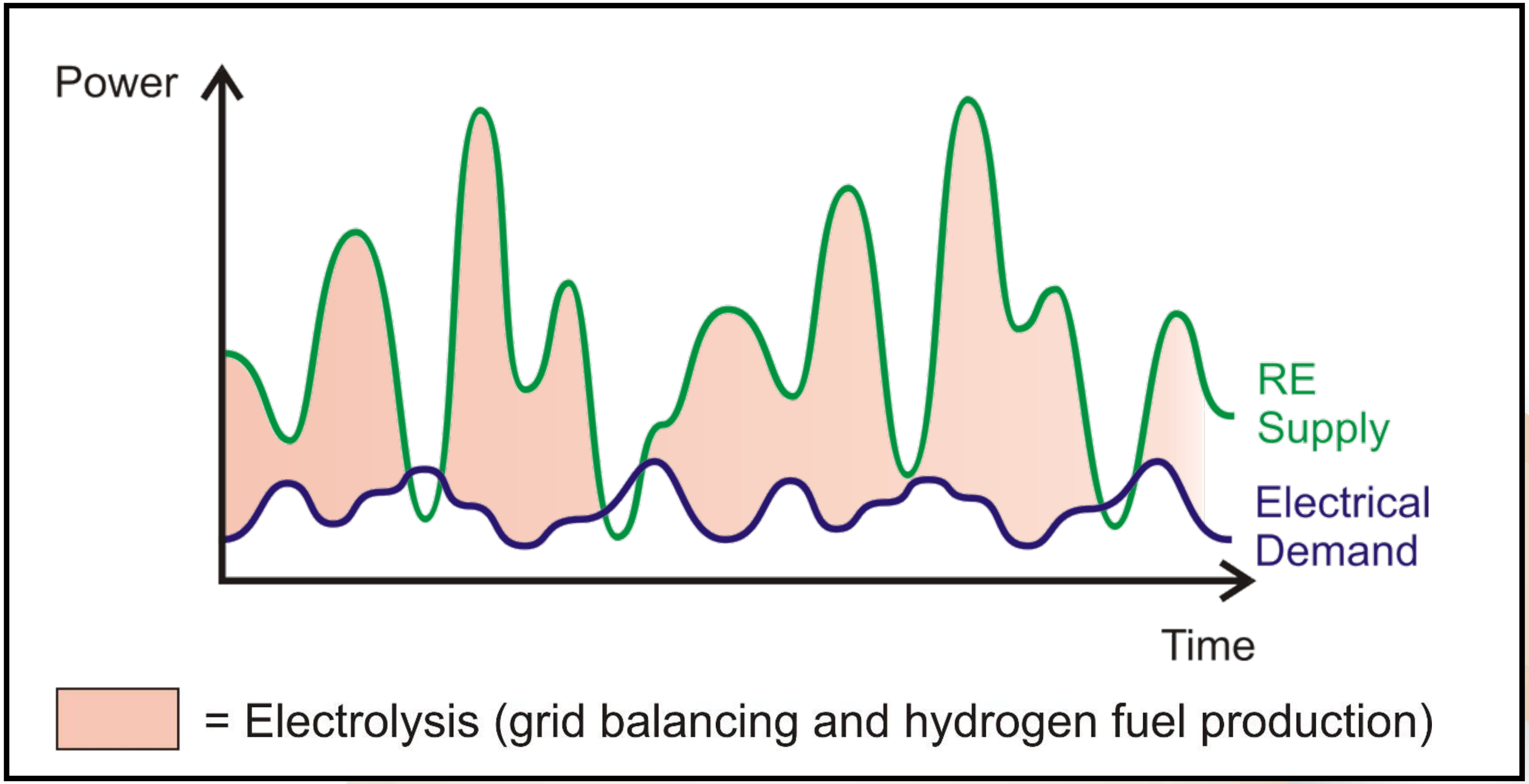
Generic System Efficiency

- Approx. 70% energy is lost in the elec-H_2-elec round-trip!

… but …

  - these losses become much less significant when H_2 transport fuel is included in the "Hydrogen Economy" model
- In moving beyond fossil fuels, energy for transport must also come from low-carbon/renewable sources
  - Demands more low-carbon/renewable primary resource (to feed both grid **and** transport)
- By including transport fuel production in the model:
  - Fuel production becomes a ***load management*** tool for more efficient use of dynamic and intermittent renewable energy
  - Reduces the size and frequency of power deficits on the electricity grid
  - Reduces the need to store grid electricity
  - Reduces wasteful elec-H_2-elec round-trip losses
  - Electricity reaching the end-user is more likely to have come directly from the source, rather than through the storage cycle
  - If, however, it has passed through the storage cycle, capturing by-product heat (CHP/F) improves efficiency
  - Storage obviates (fossil fuelled) spinning reserve
- Hydrogen transfers surplus energy from the power to the transport sector
  - Hydrogen is ***not*** generally for ***electricity*** storage

Integration of Transport



- H_2 fuel production (for transport) becomes simply a load management technique for an RE supplied grid
- H_2 is rarely, if ever, converted back to grid electricity

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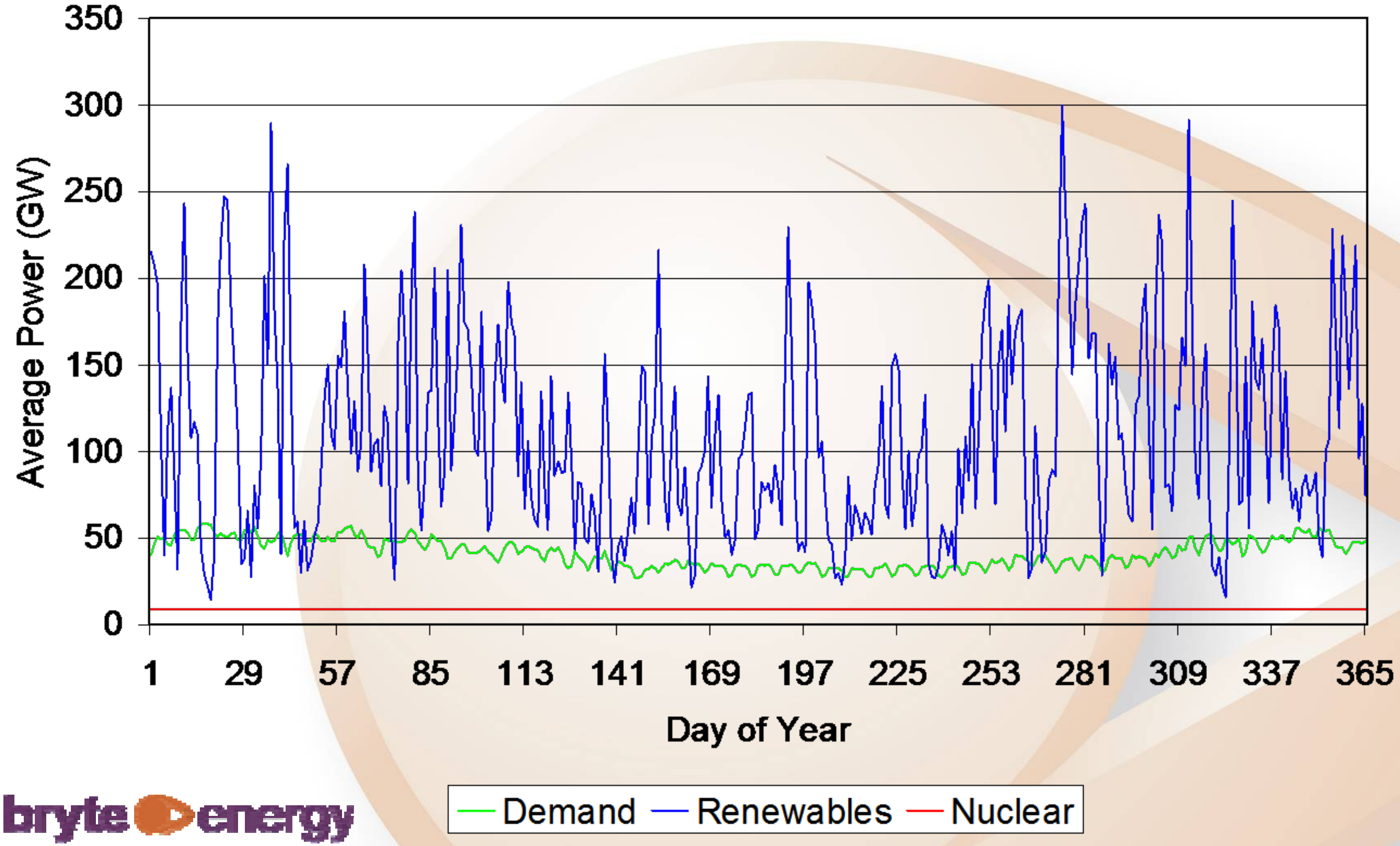
Revised H_2 Economy (National Scale)

- The UK electricity system with a very large supply of renewable energy (about 3 times average electricity demand)



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Upstream vs. Downstream

- Electrolysis better carried out downstream:
  - Aggregation of supply and demand
    - Smoothes variations
      - ~ Easier to control
      - ~ Equipment can be cheaper, longer-lasting, more reliable and more efficient
    - Greater opportunity to avoid storage
  - Hydrogen produced at the point of use
    - e.g. garage forecourts
    - Upstream electrolysis (e.g. at the wind farm) will be a niche
    - Centralised electrolysis with transmission-level pipelines for large-scale storage
- No need to build extensive hydrogen distribution-level pipelines
  - Use existing electrical networks
    - May need strengthening in places – still cheaper than building H_2 infrastructure
  - Hydrogen fuelled, domestic fuel cell CHP units unlikely to be a mainstream application
    - However, natural gas (or hythane) fuelled ones may be used extensively in short- to medium-term markets

Conclusion

- The addition of a hydrogen energy storage system has allowed a renewable energy system to operate on a stand-alone basis
- Demonstrates how energy self-sufficiency could be achieved even in an off-grid situation
- Demonstrates fundamental principles of the 'hydrogen economy' concept
  - Implications that are relevant to national-scale energy systems (hence Bryte Energy's strategic work)
- Research is ongoing, but there is significant scope for:
  - Improved energy efficiency
  - Cost reduction
  - Technical development (e.g. Bryte Energy's electrolyser development)
  - Refinement of system integration and control

Any Questions?

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Thank You for your attention